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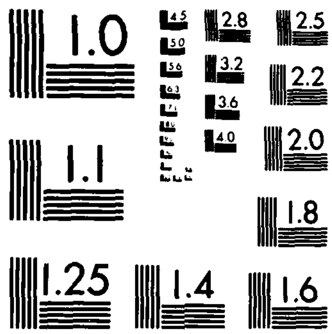
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AD-A153 092

MEASUREMENT OF EXHAUST EMISSIONS FROM DIESEL-POWERED FORKLIFTS DURING OPERATIONS IN AMMUNITION STORAGE MAGAZINES (PHASE II)

PEI ASSOCIATES

MEASUREMENT OF EXHAUST EMISSIONS FROM DIESEL-POWERED FORKLIFTS DURING OPERATIONS IN AMMUNITION STORAGE MAGAZINES (PHASE II)

Final
[redacted] Report
for the Period
July 23, 1984 to March 15, 1985

Prepared for:

U.S. Army
Belvoir Research and Development Center
Ft. Belvoir, Virginia 22060

By

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The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other documentation.

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ACKNOWLEDGMENT

PEI Associates, Inc. (formerly PEDCo Environmental, Inc.,) prepared this report for the U.S. Army Belvoir Research and Development Center (formerly MERADCOM) under Contract No. DAAK70-83-C-0133. The work effort was conducted from July 23, 1984, through March 15, 1985.

Both the planning and execution of the indoor air monitoring effort required the cooperation of a number of individuals and government agencies. We would like to identify a few individuals and agencies who were particularly helpful. We wish to thank Messrs. Tim F. Lee, Steve Moyer, and Stephen F. Sousk of Belvoir Research and Development Center for providing invaluable direction during the air quality testing of the diesel forklifts, and Messrs. John Sprague, Jerry Krohn, and Kevin White of the U.S. Army Defense Ammunition Center and School, whose cooperation and practical assistance assured a productive and timely completion of the onsite testing effort.

SUMMARY

Continuous air monitoring and breathing zone sampling were conducted in Stradley and Igloo-type ammunition magazines during the use of four different diesel-powered forklifts: a Still forklift powered by a Deutz (F3L912W) engine, a Hyster forklift powered by an Isuzu (C240) engine, a Hyster forklift powered by a Perkins (4.154) engine, and a Baker forklift powered by a Deutz (F3L912W) engine. These tests were conducted from July 23 to August 3, 1984. The monitoring was conducted during both loading/unloading and warehousing operations. Ambient windspeed, ambient and magazine temperature, and magazine ventilation airflow were also measured.

Breathing zone exposures were determined for total suspended particulate (TSP), polycyclic aromatic hydrocarbons (PAH), sulfates (SO_4^{-2}), sulfites (SO_3^{-2}), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), and odorants. Continuous monitoring of the indoor air quality was performed for the analysis of sulfur dioxide (SO_2), CO, NO, total oxides of nitrogen (NO_x), and magazine ventilation airflow.

The objectives of this investigation (identified as Phase II) were to supplement information previously collected by the U.S. Army Ft. Belvoir Research and Development Command during

tests conducted in November and December of 1983 (Phase I)[1]. The primary objectives of the Phase I investigation included: 1) to determine the ability of the forklift operations to meet Federal Occupational Safety and Health Administration (OSHA) standards and American Conference of Governmental Industrial Hygienist (AGIH) exposure limits, and 2) assess the relative "cleanliness"* of the diesel-powered test vehicles.

The results of the Phase II investigation indicated that the impact of diesel exhaust on workplace exposures and magazine air quality depend on the type of operation being performed, the type of magazine encountered, and the forklift vehicle selected for use.

Of the two ammunition-handling operations investigated, the warehousing operations present the greater potential risk to the health and safety of Army personnel. This result verified the experience gained during the Army's Phase I testing effort.

Of the two magazines in which diesel forklift operations were tested, the smaller single-door, igloo-type structure produced higher concentrations of diesel emissions and more severe breathing-zone exposures than did similar operations in double-door, Stradley-type magazines.

Based on the results of the continuous air monitoring, a performance hierarchy can be established for the vehicles tested. The order of this hierarchy as arranged in decreasing order of

* Performance as it is described here refers to the relative "cleanliness" of the vehicles as determined by their impact on magazine air quality.

performance* is: 1) the Still-Deutz vehicle, 2) the Hyster-Isuzu vehicle, 3) the Hyster-Perkins vehicle, and 4) the Baker-Deutz vehicle.**

When compared with the OSHA permissible exposure limits (PEL's) and ACGIH threshold limit values (TLV's), breathing-zone exposures and magazine air quality data indicated that under the operating conditions, ventilation, and temperatures experienced during the tests; nitric oxide, nitrogen dioxide, and carbon monoxide may pose a health risk to Army personnel in small structures similar in size and design to the Igloo-type magazines. This risk was particularly evident when the Hyster-Perkins and Baker-Deutz vehicles were being used. In a similar sense, the test data indicate that (given similar test conditions) the use of the Still-Deutz and Hyster-Isuzu vehicles in Stradley-type structures will not cause OSHA PEL's for the substances tested to be exceeded.

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* Performance as it is described here refers to the relative "cleanliness" of the vehicles as determined by their impact on magazine air quality.

** The validity of the Baker-Deutz vehicle's position in this hierarchy may be questionable; during the conduct of the test the Army was concerned that the vehicle may have functioned improperly. This belief was based on the fact that the Baker-Deutz vehicle had the same model Deutz engine as the Still-Deutz vehicle and was expected to perform in a similar manner.

I. INTRODUCTION

The U.S. Army currently uses gasoline- and electric-powered forklift trucks on a broad scale for ammunition handling operations in both the United States and Europe. Until a recent change in regulations, only electric-powered forklifts could be used inside ammunition storage magazines. Gasoline trucks have generally been used for all operations outside the magazines because of their speed and mobility advantages over electric trucks. The need to reduce or eliminate the problems associated with supporting electric forklift use at remote locations in Europe, and the need to improve the Army's ability to move large quantities of supplies rapidly, prompted an investigation to determine if electric forklifts could be replaced by diesel forklifts. As part of this investigation, a program was begun to evaluate the safety of exhaust emission levels inside ammunition magazines during the movement of large quantities of ammunition with diesel-powered forklifts.

OBJECTIVES

The objective of the investigation cited in this report (referred to as Phase II) is to supplement the initial testing conducted in November and December of 1983.[1] During that initial effort (Phase I) indoor air monitoring data was collected to assess the exhaust emission characteristics and health hazard potential of two "low emission" diesel-powered forklift trucks: a Still forklift powered by a Deutz (F3L912W) engine and a Hyster forklift powered by a Perkins (4.2032) engine. The Phase II investigation includes an assessment of the diesel exhaust emission characteristics and hazard potential from the same Still forklift, a Hyster forklift powered by a Perkins (4.154) engine, a Hyster forklift powered by an Isuzu (C240) engine and a Baker forklift powered by the Deutz (F3L912W) engine.

The Phase I investigation was designed to determine whether the Still and Hyster vehicles could operate safely in a partially enclosed area for an amount of time compatible with both normal and military mission requirements. To meet these objectives, PEI Associates, Inc. (formerly PEDCo Environmental, Inc.) conducted a series of indoor air monitoring tests at the U.S. Army Defense Ammunition Center and School near Savanna, Illinois.[1] These tests evaluated the impact of exhaust emissions from diesel-powered forklift trucks on indoor air quality in Stradley-type ammunition storage magazines.

A perceived weakness of the Phase I investigation was the unfortunate weather conditions encountered during the test period. Average daily wind speeds were recorded at velocities of 20 mph with gusts up to 30 mph with ambient temperatures ranging between 12° and 40°F. Because the exact effect of these extremes on key test parameters, in particular, the engine performance and magazine air change rates could not be determined with certainty, it was recommended that another set of tests be conducted under less severe weather conditions.[1] It is this

Oxides of Nitrogen--

A Bendix 8101-B chemiluminescent analyzer was used for the continuous monitoring of NO and NO_2. The measurement principle of this instrument is based on the chemiluminescent reaction between NO and ozone (O_3) according to the reaction:

$$NO + O_3 \rightarrow NO_2 + O_2 + H_V$$

Light emissions result when the electronically excited NO_2 molecules revert to their ground state. A catalytic converter is used to convert NO_2 present in the air sample to NO before it enters the reaction chamber. The amount of NO_2 is then determined by subtracting the NO measurement from the NO_x measurement. The analyzer provides automatic cycling through the NO and NO_x measurements, and the output difference (NO_2) is updated after each cycle. The initial operating ranges used during the testing were 0 to 0.5, 1, and 2 ppm; with a minimum detection limit of 0.005 ppm. Because oxides of nitrogen concentrations above 2.0 ppm were observed, the instrument was adjusted to read concentrations up to 8.5 ppm during the second day of loading/unloading operations. During warehousing operations where higher concentrations are expected, the instrument's range was increased to 17.5 ppm full scale. This instrument is certified by the EPA as a reference method for the measurement of oxides of nitrogen.

DATA COLLECTION

Continuous and breathing zone data were collected for both loading/unloading and warehousing operations in two Stradley and obtained a sample(s). The instrument's response was then transferred to a strip chart for recording. The simplicity and the singular nature of the sampling task at Igloo-type magazines (NO/NO_x analysis only) did not require use of the computer-controlled sampling system presented in Figure 2.

A description of each continuous monitoring instrument and its limits of detection are presented in the following subsections.

Sulfur Dioxide--

A Beckman Model 953 fluorescent analyzer was used for the continuous monitoring of SO_2. The measurement principle of this instrument is based on the fluorescence of SO_2 molecules when irradiated with ultraviolet light. Operating ranges of 0 to 1.0, 0 to 20.0, and 0 to 6.0 ppm SO_2 were obtained with a minimum detection limit of 0.005, 0.010, and 0.030 ppm respectively. This instrument is certified by the U.S. Environmental Protection Agency (EPA) as a reference method for the measurement of sulfur dioxide.

Carbon Monoxide--

A Bendix Model 8501-5CA analyzer was used for the continuous monitoring of CO. The measurement principle of this instrument is based on the absorption of infrared radiation by CO in a nondispersive photometer. An operating range of 0 to 50 ppm CO was achieved with a minimum detection limit of 0.5 ppm. This instrument is certified by the U.S. EPA as a reference method for the measurement of carbon monoxide.

through ½-inch I.D. Teflon tubing at a rate of 10 liters/min. At the mobile laboratory each sample line was connected to a two-way solenoid valve. The solenoid is open when in an unactivated condition and is then purging the sampling lines. Each valve setting is activated by the programmed data-acquisition system in a predetermined time sequence. Prior to activation, the valve to the manifold is closed and the valve to the exhaust is opened, thus allowing a constant flow of sample air through the sample lines. Upon activation, the valve to the exhaust is closed and the valve to the manifold is opened. Sample air is passed through the manifold at a rate of 10 liters/min. This system permits the air in the manifold to be changed at least once every 5 seconds. The analytical instruments then draw air from the manifold. After a programmed sampling period, the computer activates the valves on the next sampling line, while returning the first sample line to a purge condition. In addition to the monitoring of magazine air, the data on the velocity through each magazine's ventilation duct were collected and stored by the computer system. Wind speed, wind direction, and temperature in and out of the magazines were recorded on strip charts.

The continuous monitoring system used in the Igloo-type magazines consisted of a simplified, one instrument system. Air samples from the magazine were carried through ½ inch I.D. Teflon tubing at a rate of 10 liters/min. The tubing lead to a manifold from which a single continuous NO/NO_x analytical instrument

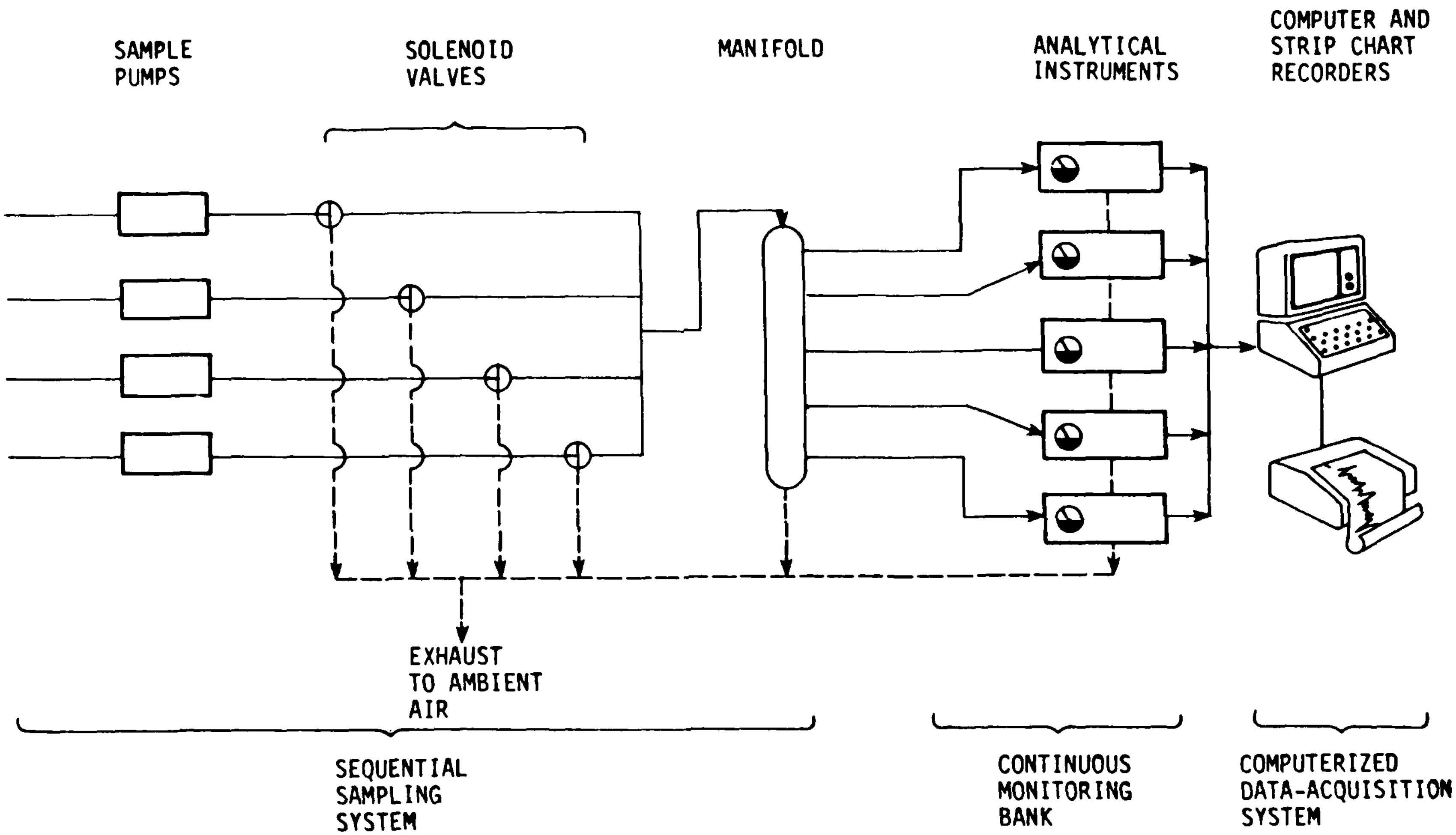

Figure 2. Sampling system for continuous monitors.

the necessary apparatus would have seriously interfered with normal working activities and may have affected the safe operation of the forklift vehicles. To avoid these problems, sampling apparatus were mounted directly on the forklift trucks, but situated so the point of collection for each apparatus was located in the breathing zone of the forklift operators.

Continuous Monitoring

As in the case of the Phase I investigation, a temperature-controlled mobile laboratory was positioned next to two Stradley-type ammunition magazines and was used to house the data-acquisition computer and continuous-monitoring equipment. A continuous sampling system was used in conjunction with a programmable solenoid switching mechanism to collect air within the magazine. Air samples from locations inside the magazines were carried through Teflon sample lines to the programmable switching system located within the mobile lab. The continuous monitors drew air samples from a common manifold to analyze the air for concentrations of CO, SO_2, NO and NO_x. Data were collected by a computerized data-acquisition system backed up by strip chart recorders. A description of the operation of the computerized data-acquisition system is presented in Appendix B.

The continuous monitoring system used for the Stradley-type magazine, was comprised of three elements: a sequential sampling system, a bank of continuous monitors, and a computerized data-acquisition system. A schematic representation of the sequential sampling system is presented in Figure 2. Air samples from up to four individual locations (two in each magazine) can be carried

TABLE 2. SAMPLING AND ANALYTICAL METHODS FOR DETERMINING WORKER EXPOSURES TO DIESEL EXHAUST COMPONENTS[a]

Exhaust component tested	Personal sampling method	Analytical method	Reference number[b]
Particulates			
Insoluble fraction			
Total suspended particulates (TSP)[c]	Filter	Gravimertric	329 (SDS)
Soluble fraction			
Polycyclic aromatic hydrocarbons (PAH)	Filter (Soxhlet extraction)	High-pressure liquid chromatography	-
Gases			
Carbon monoxide (CO)[d]	Continuous monitor	Direct reading (dosimetry)	-
Nitrogen dioxide and nitric oxide	Solid sorbent (triethanolamine extract)	Spectrophotometry	PCAM231
Sulfur acid (as SO_4^{-2})	Filter	Titration	S174
Sulfite (SO_3^{-2})	Filter	Titration	S174
Other			
Odorants	Chromosorb 102	Liquid phase chromotography	e

[a] NIOSH Manual of Analytical Methods
U.S. Department of Health and Human Services
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health, August 1981.

[b] Method identification number for NIOSH unless otherwise specified.

[c] Known human irritant.

[d] Carbon monoxide was monitored with portable, continuous, real-time electronic monitoring equipment.

[e] DOAS method (Ref. 7).

SAMPLING AND ANALYTICAL METHODS

A brief review of the sampling and analytical methods used during this investigation is presented here. A more detailed description of the methods used for breathing zone monitoring are presented in Appendix A.

Breathing Zone (Personal) Monitoring

Breathing zone monitoring was conducted on Army personnel involved in the ammunition handling operation. The objective of this monitoring effort was to determine time-weighted average (TWA) exposures to diesel exhaust components and compare these exposures with OSHA-PEL's and ACGIH-TLV's. The sampling and analytical methods used during the breathing zone monitoring effort are National Institute for Occupational Safety and Health (NIOSH)-approved techniques.[6] The monitoring apparatus consisted of real-time electronic dosimeters for CO; constant hi-flow pumps for TSP, SO_4^{-2} and SO_3^{-2}; and low-flow, constant-stroke pumps for NO, NO_2, and PAH. Odorants were sampled using a modified DOAS method.[7] The personal sampling methods and analytical procedures used for each exhaust component are summarized in Table 2.

The analysis of samples taken during the personal monitoring effort was conducted at PEI's analytical laboratory according to the prescribed reference analytical methods.[6,7] This laboratory is accredited by the American Industrial Hygiene Association (AIHA) and participates in the NIOSH Proficiency Analytical Testing (PAT) program.

Because of the variety of collection methods required for the personal monitoring, directly equipping Army personnel with

TABLE 1. DIESEL EXHAUST COMPONENTS TESTED: THEIR RELEVANT HEALTH EFFECTS AND TARGET ORGANS[a]

Exhaust component tested	Relevant health effects	Target organs
Particulates		
Insoluble fraction		
Total suspended particulates (TSP)	Eye and mucous membrane irritation	Respiratory system, eyes, throat
Soluble fraction		
Polycyclic aromatic hydrocarbons (PAH)	Systemic toxicity and carcinogenicity	Respiratory system, liver
Gases		
Carbon monoxide (CO)	Vertigo, tachypnea, depression, angina, syncope, asphyxia	Respiratory, cardiovascular, and central nervous systems; blood
Carbon dioxide (CO_2)	Vertigo, restlessness, paresthesia, dyspnea, asphyxia, coma	Respiratory and cardiovascular systems, skin
Nitrogen dioxide, as oxides of nitrogen (NO_x)	Eye irritation, dyspnea, pulmonary edema, tachypnea, tachycardia	Respiratory and cardiovascular systems
Sulfur dioxide (SO_2)	Mucous membrane and pulmonary irritation, bronchoconstriction	Respiratory system, skin, eyes
Sulfur acid, as sulfate (SO_4^{-2})	Mucous membrane and pulmonary irritation, pulmonary edema, emphysema, dental errosion	Respiratory system, skin, teeth
Other		
Total hydrocarbons (THC)	Vertigo, eye and mucous membrane irritation, numbness	Respiratory system, skin, eyes
Odorants	Some irritation, psychosomatic effects	Olfactory senses

[a] Chemical Hazards, National Institute for Occupational Safety and Health and the Occupational Safety and Health Administration. DHEW (NIOSH) Publication No. 78-210, August 1981.

operations during the execution of a military mission by adversely affecting morale. Final selection of exhaust components to be tested was also based on the availability of accurate and reliable methods of sampling and analysis.

Table 1 presents the diesel exhaust components tested during the Phase I investigation and their relevant health effects. These components include both airborne particulates and gaseous substances generated during the operation of diesel engines.

Following the results of the Phase I investigation it was decided that carbon dioxide (CO_2) and total hydrocarbons (THC) should be dropped from consideration during the Phase II testing. This decision was based on the relatively low toxicity of the pollutants and the very low airborne concentrations detected during the Phase I effort: peak CO_2 concentrations were detected at levels less than 30 percent of the OSHA standard (5000 ppm), while THC levels were found at concentrations below 12 ppm.

Although none of the substances monitored during Phase I were found at levels in excess of OSHA-permissable exposure limits (PELs)[3] or AGCIH-threshold limit values (TLV's),[4] it was considered prudent to continue testing for the more toxic constituents: carbon monoxide (CO), sulfur dioxide (SO_2), nitric oxide (NO), and nitrogen dioxide (NO_2).[5] Strong irritants were also reconsidered for inclusion in the Phase II testing: total suspended particulates (TSP), sulfur acid (as sulfate SO_4^{-2}) and sulfites (SO_3^{-2}).

A sub-set of the Phase II tests were conducted in "Igloo-type" magazines. These smaller structures represent older magazines having only 12,500 ft^3 of storage space. The Igloo-type magazine is 60 feet long, 25 feet wide and has no sidewalls. The arched roof starts at the floor and rises above the magazine floor to the height of 13 feet at its centerline. The single-door opening at one end is approximately 8 feet high by 4 feet wide.

COMPONENTS OF DIESEL EXHAUST

Toxicological research programs are currently attempting to determine if diesel vehicle emissions have physical or chemical properties that would make them significantly more toxic than other combustion products associated with the use of fossil fuels. To date, however, no unique compounds have been identified in diesel emissions that present new concerns.[2] Despite the lack of conclusive research, some measurement of airborne contamination was believed necessary to ensure that the diesel-powered equipment the Army plans to purchase will not adversely affect the health of its personnel. A number of chemical substances were considered prime candidates for testing, based on a substance's capacity for producing: 1) a serious health hazard, 2) having an irritant effect, or 3) generating a noxious odor. Concern about a substance's toxic effects is obvious; the health and safety of Army personnel are important during both normal and combat service support operations. Irritant effects and noxious odors are important because their presence could hinder forklift

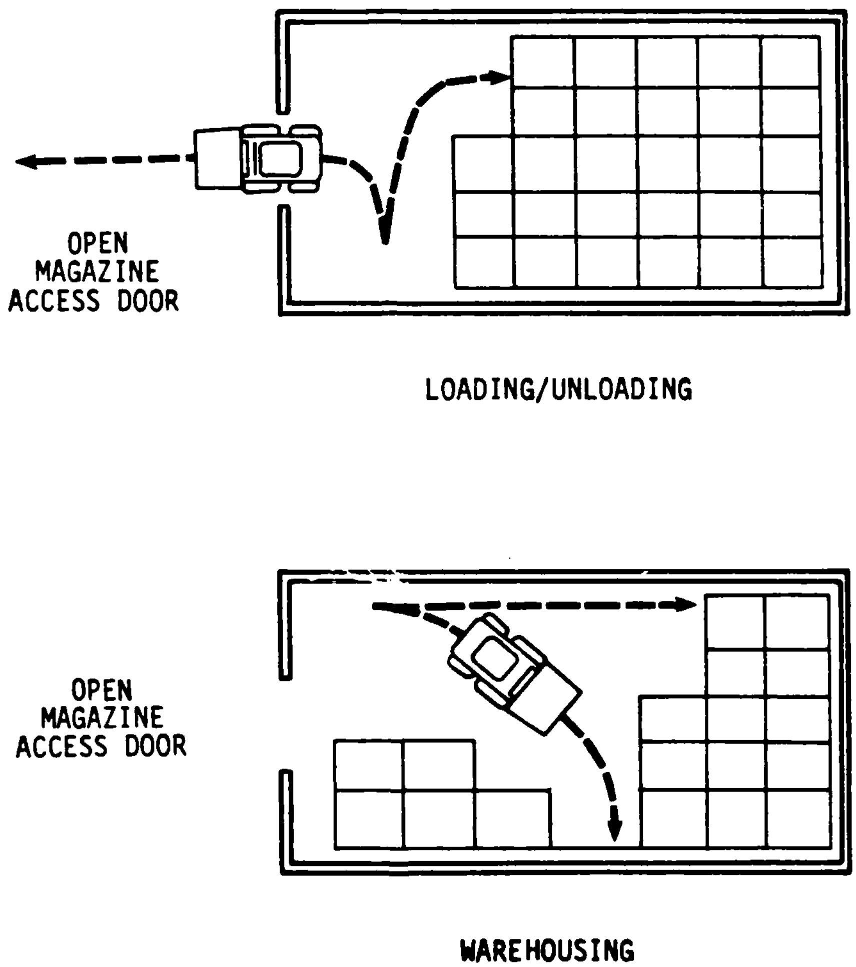

Figure 1. Two model scenarios for the operation and movement of forklift trucks in ammunition storage magazines.

unloaded, transfers the load to or from a vehicle, and returns loaded or empty).

Warehousing operations involve the movement of ammunition, but only within the magazine. The activity of a forklift truck during warehousing operations is substantially different from that during loading/unloading operations. Although the warehousing operation can be divided into the same three activity modes, all three modes are performed within the magazine and load transfer is performed twice for each load being handled.

Although any given forklift operation can vary from the two model scenarios presented above, it is believed that these models cover the range of all operations and thus present a reasonably accurate picture of what most operations are likely to involve. Figure 1 is a pictorial representation of the two model scenarios.

STORAGE MAGAZINES

Unlike the Phase I effort which dealt only with Stradley-type magazines, two different types of ammunition storage magazines were considered during Phase II.

A majority of the tests were conducted in "Stradley-type" magazines. These structures are large magazines with approximately 24,000 ft^3 of storage space. The Stradley-type magazine is 80 feet long, 25 feet wide, has an 8 feet high sidewall supporting an arched roof whose center line is 12 feet above the magazine's floor. The large "double door" opening at one end is approximately 10 feet high by 10 feet wide.

II. INVESTIGATION

OPERATION OF FORKLIFT TRUCKS IN AMMUNITION STORAGE MAGAZINES

Two model scenarios were presented during the initial (Phase I) investigation to characterize the operation and movement of forklift trucks in ammunition storage magazines. The first, which is described as a loading/unloading operation, is characterized by the movement of supplies in and out of a magazine. The second, which is described as a warehousing operation, involves the movement or rearranging of supplies within a magazine.

The loading/unloading operation is typified by the movement of supplies out of the magazine to waiting transport vehicles or into the magazine from the same vehicles. The activity of a forklift truck during loading/unloading operations can be classified into three modes: 1) movement while empty, 2) movement under loaded conditions, and 3) activities involving load transfer. During a loading/unloading operation the three modes are each performed once while the vehicle is inside the magazine (i.e., the vehicle enters the magazine in either a loaded or unloaded condition, transfers the load to or from storage inside the magazine, and leaves the magazine either loaded or empty, depending on its mission) and once while the vehicle is outside the magazine (i.e., the vehicle leaves the magazine loaded or second set of tests (Phase II) which is the subject of this report.

The data from both phases of the Army's investigation are to be used: 1) to determine the ability of the forklift operations to meet Federal OSHA standards, 2) to assess the relative "cleanliness" of the test vehicles, and 3) to provide a data base from which the Belvoir R&D Center could validate a predictive model designed to estimate indoor air quality at ammunition magazines.

SCOPE OF WORK

The scope of work for Phase II was similar in nature to the Phase I effort and covered the following tasks:

a) Initial familiarization with the use of a forklift truck during operations in ammunition storage magazines.

b) Generation of a list of exhaust components to be sampled and explain why each should be monitored.

c) Development of a detailed test plan for measuring and analyzing each of the specified diesel exhaust components. Determine the type of test to be used; procedures and techniques for taking air samples; and the methodology, procedures, and equipment to be used for analysis and characterization of the samples taken.

d) Conduct of indoor air quality monitoring tests during simulated ammunition handling operations at the U.S. Army Defense Ammunition Center and School near Savannah, Illinois.

e) Analysis of the indoor air quality data obtained during the test and, where applicable, comparison it with Federal OSHA permissible exposure limits (PELs).

f) Provision of technical input that can enable the Army to determine whether a diesel-powered forklift truck, based on its emission output, is suitable for operations in ammunition storage magazines.

one Igloo-type magazines. The tests were conducted over a 10-day period starting on July 23, 1984, and ending on August 3, 1984. Table 3 presents a schedule of the tests performed during the Phase II investigation. The continuous and breathing zone data were taken to characterize 6 unloading operations, 6 loading operations and 28 warehousing operations. These 40 operational events were monitored during 30 individual tests.

OPERATIONS IN STRADLEY-TYPE MAGAZINE

The typical unloading/loading operation in a Stradley-type magazine was accomplished using two magazines. Using a forklift, 404 pallets of 105 mm ammunition were unloaded from a magazine of 510 pallets (i.e., until the contents was reduced to 106 pallets). The loads were transferred to a second forklift and loaded into an adjacent magazine. The second magazine contained an initial stock of 106 pallets prior to the start of the loading activities. This residual volume of ammunition was left in place in order to mimic the activities performed during the Phase I investigation.* The average time for accomplishing a loading/unloading operation in Stradley-type magazines was 8 hours and 13 minutes; ranging from 7 hours and 35 minutes to 8 hours and 35 minutes.

*During the Phase I investigation only pallets containing older 90 mm ammunition were available for handling. This ammunition was boxed in large containers requiring more space per pallet than the newer 105 mm ammunition. In order to keep the number of vehicle trips in and out of the magazine constant, only 404 of the 105 mm pallets were moved during any single operation.

TABLE 3. SCHEDULE OF TEST OPERATIONS

Test number	Date	Operation/vehicle	Magazine/ sampling location
1	7/23/84	Unloading - Still/Deutz (No. 1)	Stradley (B) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (B) - Rear
		Loading - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Loading - Hyster/Isuzu (No. 2)	Stradley (A) - Rear
2	7/24/84	Unloading - Still/Deutz (No. 1)	Stradley (A) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (A) - Rear
		Loading - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Loading - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
3	7/24/84	Warehousing - Hyster/Perkins (No. 3)	Igloo (C) - Center
4	7/25/84	Unloading - Still/Deutz (No. 1)	Stradley (B) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (B) - Rear
		Loading - Hyster/Perkins (No. 3)	Stradley (A) - Forward
		Loading - Hyster/Perkins (No. 3)	Stradley (A) - Rear
5	7/25/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
6	7/26/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
7	7/26/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
8	7/27/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Rear
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
9	7/27/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Rear
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Rear

TABLE 3 (continued)

Test number	Date	Operation/vehicle	Magazine/ sampling location
10	7/30/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Forward
11	7/30/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Forward
12	7/30/84	Warehousing - Baker/Deutz (No. 4)	Igloo (C) - Center
13	7/31/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (B) - Forward
14	7/31/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
15	7/31/84	Warehousing - Hyster/Perkins (No. 3)	Igloo (C) - Center
16	7/31/84	Unloading - Hyster/Perkins (No. 3)	Igloo (C) - Center
17	7/31/84	Loading - Hyster/Perkins (No. 3)	Igloo (C) - Center
18	8/1/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (B) - Rear
19	8/1/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Rear
20	8/1/84	Unloading - Hyster/Isuzu (No. 2)	Igloo (C) - Center
21	8/1/84	Loading - Hyster/Isuzu (No. 2)	Igloo (C) - Center
22	8/1/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
23	8/2/84	Unloading - Baker/Deutz (No. 4)	Igloo (C) - Center

TABLE 3 (continued)

Test number	Date	Operation/vehicle	Magazine/ sampling location
24	8/2/84	Loading - Baker/Deutz (No. 4)	Igloo (C) - Center
25	8/3/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
26	8/3/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Forward
27	8/3/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
28	8/3/84	Warehousing - Baker/Deutz (No. 4)	Igloo (C) - Center
29	8/3/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
30	8/3/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward

The typical warehousing operation in a Stradley-type magazine was accomplished by transferring pallets with a single forklift vehicle back and forth within the magazine. The duration of a warehousing operation varies greatly, depending on the purpose of the operation and the extent of reorganization necessary. The warehousing tests performed in Stradley-type magazines averaged 2 hours and 57 minutes, ranging from 1 hour and 5 minutes to 4 hours.

OPERATIONS IN IGLOO-TYPE MAGAZINES

The loading/unloading and warehousing operations performed in Igloo-type magazines were conducted using 82 pallets of 105 mm ammunition. During the loading/unloading operation all 82 pallets were removed from or returned to the magazine. The pallets were reorganized within the magazine during warehousing operations. The loading/unloading operations performed in the Igloo-type magazine averaged 1 hour and 47 minutes, ranging from 1 hour and 30 minutes to 2 hours and 10 minutes. The warehousing tests averaged 1 hour and 36 minutes, ranging from 2 hours and 50 minutes to 40 minutes. This 40-minute effort did not constitute a normal warehousing operation, since it was halted prematurely due to the accumulation of NO and NO_x inside the magazine.

III. RESULTS

Four diesel-powered forklift trucks were tested during the second phase of the investigation:

- Vehicle Number 1: a Still forklift powered by a Deutz (F3L912W) engine
- Vehicle Number 2: a Hyster forklift powered by an Isuzu (C240) engine
- Vehicle Number 3: a Hyster forklift powered by a Perkins (4.154) engine
- Vehicle Number 4: a Baker forklift powered by a Deutz (F3L912W) engine

Breathing zone results are presented in this section in their entirety. Summaries of the continuous air monitoring data are presented in this section, while the raw data from the tests are presented in Appendix B at the end of the report.

BREATHING ZONE SAMPLES

Breathing zone air samples representative of vehicle driver exposures were taken during each of the ammunition handling operations. From the results of these air samples, time-weighted averages were determined for comparison with OSHA-PEL's,[3] and ACGIH-TLV's.[4]

Sampling in Stradley-Type Magazines

Table 4 summarizes the exposure of drivers to diesel exhaust during loading/unloading operations in Stradley-type magazines. Exposure to five exhaust components is reported; total suspended

TABLE 4. BREATHING ZONE EXPOSURES DURING LOADING/UNLOADING OPERATIONS IN STRADLEY-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Sampling duration, min.	Particulate, mg/m^3	Sulfate, mg/m^3	Sulfite, mg/m^3	Nitric oxide, mg/m^3	Nitrogen dioxide, mg/m^3
Still-Deutz (number 1)	1*	458	0.78	<0.02[a]	<0.04[a]	1.65	0.17
	2*	489	0.61	<0.02[a]	<0.01[a]	1.01	0.20
	4	495	1.19	0.02	<0.01[a]	0.64	0.12
Hyster-Isuzu (number 2)	1*	458	0.61	<0.02[a]	<0.04[a]	1.37	0.27
	2*	491	0.60	<0.02[a]	<0.01[a]	0.64	0.18
Hyster-Perkins (number 3)	4	675	1.20	<0.01[a]	<0.01[a]	0.62	0.19

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Value indicates that the substance may be present at a concentration less than the detection limit of the combined sampling and analytical method. Variations in the reported detection limit are due to the difference in the sample air volume collected during individual tests.

particulates (TSP), sulfates (SO_4^{-2}), sulfites (SO_3^{-2}), nitric oxide (NO) and nitrogen dioxide (NO_2). Personal exposures to carbon monoxide (CO) were not collected because of dosimeter instrument malfunctions. Concentrations of polycyclic aromatic hydrocarbons (PAH) and odorants were determined to be below the detection limit of the analytical methods for all the samples (see Appendix A).

Tables 5 and 6 summarize the exposure of drivers to diesel exhaust during warehousing operations in Stradley-type magazines. Concentrations of six exhaust components are reported in Table 5: TSP, SO_4^{-2}, SO_3^{-2}, NO, NO_2 and CO. The carbon monoxide exposures summarized in Table 6 are presented by time-weighted average, highest 15-minute, and instantaneous peak concentrations. PAH and odorants were not captured in sufficient amounts for detection by the analytical methods used.

Sampling in Igloo-Type Magazines

Tables 7 and 8 summarize the exposure of drivers to diesel exhaust during loading/unloading operations in Igloo-type magazines. Six exhaust components are reported in Table 7: TSP, SO_4^{-2}, SO_3^{-2}, NO, NO_2 and CO. The carbon monoxide exposures are summarized in Table 8 by time-weighted average, highest 15 minute, and instantaneous peak concentrations. PAH and odorants were not captured in sufficient amounts for detection by the analytical methods used.

Tables 9 and 10 summarize the exposure of drivers to diesel exhaust during warehousing operations in Igloo-type magazines.

TABLE 5. BREATHING ZONE EXPOSURES DURING WAREHOUSING OPERATIONS IN STRADLEY-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Sampling duration, min.	Particulate, mg/m^3	Sulfate, mg/m^3	Sulfite, mg/m^3	Nitric oxide, mg/m^3	Nitrogen dioxide, mg/m^3
Hyster-Isuzu (number 2)	6	193	0.45	0.05	<0.02[a]	1.57	0.65
	8	181	0.57	0.06	<0.02[a]	2.98	0.94
	9	183	0.94	0.05	<0.02[a]	3.33	0.94
	10	185	b	0.05	<0.02[a]	5.25	1.22
	11	193	b	0.08	0.03	5.47	1.61
	13	184	0.72	0.06	<0.02[a]	4.42	1.46
	14	182	0.59	0.06	<0.02[a]	4.75	1.64
	29*	182	0.96	0.12	<0.02[a]	5.86	1.92
Hyster-Perkins (number 3)	8	185	2.59	0.02	<0.02[a]	3.15	0.75
	9	186	1.99	0.02	<0.02[a]	3.03	0.88
	10	180	b	0.04	<0.02[a]	7.16	1.41
	11	188	b	0.08	<0.02[a]	6.85	1.74
	18	103	3.79	0.03[a]	<0.03[a]	9.09	1.86
	26	196	0.55	0.09[a]	<0.09[a]	5.07	1.28
Baker-Deutz (number 4)	13	180	2.02	0.07	<0.04	10.03	1.66
	14	183	4.96	0.08	<0.02[a]	4.42	2.54
	18	181	1.55	0.10	<0.02[a]	11.54	1.84
	19	180	3.13	0.10	<0.02[a]	13.64	2.24
	25*	225	c	0.06	<0.02[a]	8.40	1.33
	30*	281	c	0.58	<0.02[a]	9.91	1.64

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Value indicates that the substance may be present at a concentration less than the detection limit of the combined sampling and analytical method. Variations in the reported detection limit are due to the difference in the sample air volume collected during individual tests.

[b]Sample destroyed during analysis.

[c]No data collected.

TABLE 6. BREATHING ZONE EXPOSURES TO CARBON MONOXIDE DURING WAREHOUSING OPERATIONS IN STRADLEY-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Carbon monoxide			
		Sampling duration, min.	Time-weighted average, ppm	15 minute concentration, ppm	Peak concentration, ppm
Hyster-Isuzu (number 2)	6	210	<1.0[a]	<1.0[a]	<1.0[a]
	8	140	2.5	2.5	17.5
	9	182	2.5	5.0	20.0
	29*	182	2.5	5.0	20.0
Hyster-Perkins (number 3)	8	149	<1.0[a]	<2.5[a]	12.5
	9	185	2.5	5.0	20.0
	10	138	a	a	a
	11	188	7.5	10.0	12.5
	18	108	40.0	42.5	132.5
	26	76	37.5	45.0	47.5
Baker-Deutz (number 4)	13	204	37.5	57.5	110.0
	18	229	30.0	40.0	155.0
	25*	116	20.0	32.5	187.5

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Breathing zone concentration is below the detection limit of the instrument.

[b]Data was not collected due to malfunctioning of the equipment.

TABLE 7. BREATHING ZONE EXPOSURES DURING LOADING/UNLOADING OPERATIONS IN IGLOO-TYPE MAGAZINES[†]

Vehicle type, body-engine	Test number	Sampling duration, min.	Particulate, mg/m^3	Sulfate, mg/m^3	Sulfite, mg/m^3	Nitric oxide, mg/m^3	Nitrogen dioxide, mg/m^3
Hyster-Isuzu (number 2)	20, 21	274	a	0.05	<0.01[b]	2.19	0.68
Hyster-Perkins (number 3)	16, 17	90	a	0.22	<0.03	7.46	3.06
Baker-Deutz (number 4)	23, 24	225	3.04	0.04	<0.03	7.45	1.47

[†]All tests were performed with vehicles using low sulfur level (see Appendix C).

[a]Data not collected.

[b]Value indicates that the substance may be present at a concentration less than the detection limit of the combined sampling and analytical method. Variations in the reported detection limit are due to the difference in the sample air volume collected during individual tests.

TABLE 8. BREATHING ZONE EXPOSURES TO CARBON MONOXIDE DURING LOADING/UNLOADING OPERATIONS IN IGLOO-TYPE MAGAZINES[+]

Vehicle type, body-engine	Test number	Carbon monoxide			
		Sampling duration, min.*	Time-weighted average, ppm	15 minute concentration, ppm	Peak concentration, ppm
Hyster-Isuzu (number 2)	20, 21	279	2.5	5.0	17.5
Hyster-Perkins (number 3)	16, 17	274	2.5	10.0	120.0
Baker-Deutz (number 4)	23, 24	508	5.0	12.5	27.5

[+]All tests were performed with vehicles using low sulfur fuel (see Appendix C).

*Sampling duration included time for start-up, length of the first test, a short transition period, length of the second test, and close-out of the second test. Due to the manner in which the data were collected, the sampling duration could not be broken out in any greater detail.

TABLE 9. BREATHING ZONE EXPOSURES DURING WAREHOUSING OPERATIONS IN IGLOO-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Sampling duration, min.	Particulate, mg/m^3	Sulfate, mg/m^3	Sulfite, mg/m^3	Nitric oxide, mg/m^3	Nitrogen dioxide, mg/m^3
Hyster-Isuzu (number 2)	5	120	a	0.14	<0.04[b]	11.11	3.57
	7	96	1.14	<0.04[b]	<0.04[b]	9.34	2.94
	22	90	a	0.11	<0.04[a]	6.33	3.50
	27*	121	1.61	0.18	0.06	10.03	2.72
Hyster-Perkins (number 3)	3	68	a	<0.05[b]	<0.06[b]	6.61	2.72
	15	101	a	0.22	<0.03[b]	17.46	4.51
Baker-Deutz (number 4)	12	180	a	0.13	<0.02[b]	26.62	7.70
	28*	34	a	<0.09[b]	<0.09[b]	13.48	3.23

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]No data collected.

[b]Value indicates that the substance may be present at a concentration less than the detection limit of the combined sampling and analytical method. Variations in the reported detection limit are due to the difference in the sample air volume collected during individual tests.

TABLE 10. BREATHING ZONE EXPOSURES TO CARBON MONOXIDE DURING WAREHOUSING OPERATIONS IN IGLOO-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Carbon monoxide			
		Sampling duration, min.	Time-weighted average, ppm	15 minute concentration, ppm	Peak concentration, ppm
Hyster-Isuzu (number 2)	5	120	a	a	a
	7	125	2.5	7.5	10.0
	22	96	12.5	15.0	42.5
	27*	156	5.0	12.5	22.5
Hyster-Perkins (number 3)	3	68	a	a	a
	15	46	12.5	20.0	117.5
Baker-Deutz (number 4)	12	197	15.0	20.0	95.0
	28*	46	50.0	57.5	62.5

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]No data was collected.

vehicle (Table 12, test 26). No continuous air monitoring for CO was conducted in Igloo-type magazines.

Sulfur Dioxide

Sulfur dioxide (SO_2) levels were determined with continuous air monitoring instruments only. This limitation was imposed because during the Phase I effort breathing zone exposures were never recorded above the detection limits of the sampling and analytical method. The continuous monitoring data indicated that the mean test concentrations of SO_2 were less than 35 percent of the OSHA-PEL. When only tests conducted with low sulfur fuel are considered, this percentage drops to 25 percent.

Odorants

Samples of diesel exhaust were collected on Chromosorb 102 adsorbent for analysis using the Diesel Odor Analysis System (DOAS).[7] Analysis of samples did not detect concentrations above the detection limits for any of the polar oxygenated fractions associated with noxious diesel odors. Although during some warehousing operations a slight "diesel" odor was observed by the PEI field personnel, the lack of any distinctive odor during a majority of the tests agreed with the findings of the DOAS samples (i.e., below detection).

COMPARISON OF FORKLIFT EMISSION LEVELS

Comparison of emission levels (continuous monitoring data) from the four diesel-powered forklifts indicates that a performance hierarchy can be established among the vehicles. Although very limited data were collected on the Still-Deutz vehicle due nitrogen (NO_x) readings averaged about 10 to 20 percent, a review of the testing data (Tables 11 through 14) indicates that the contribution of NO_2 ranged from values as low as 1 percent to values as high as 50 percent of the NO_x reading. The maximum reading: 1.55 mg/m^3 (Table 14; test 5), represents only 15 percent of the OSHA-PEL and 25 percent of the ACGIH-TLV.

Carbon Monoxide

Carbon monoxide (CO) may present an exposure problem during some operations. Although no breathing zone exposures exceeded the OSHA-PEL, one test during a warehousing operation in an Igloo-type magazine using a Baker-Deutz vehicle (Table 10; test 28), reached a three and one-half hour time-weighted average of 50 ppm. The ACGIH fifteen minute short-term exposure limit (STEL) of 400 ppm was never exceeded, the maximum 15 minute exposure was 14 percent of the STEL (Table 6; test 13 and Table 10; test 28). Instantaneous peak concentrations above 100 ppm occurred frequently during the exposure monitoring. The maximum peak concentration of 187.5 ppm occurred during warehousing operations in a Stradley-type magazine using a Baker-Deutz vehicle (Table 6; test 25).

Continuous monitoring of the magazine for CO indicates that the mean indoor air quality during operations inside Stradley-type magazines never exceed 20 percent of the OSHA-PEL. The maximum reading was 9.3 ppm and occurred during warehousing operations in a Stradley-type magazine using a Hyster-Perkins mean indoor air quality during both warehousing and loading/unloading activities is unlikely to exceed 50 percent of the OSHA-PEL or ACGIH-TLV (Tables 11 and 12). However, during the warehousing operations in Igloo-type magazines, the air quality exceeded 50 percent of the OSHA-PEL for nitric oxide (Table 14; test 3, test 12, and test 28).

Nitrogen Dioxide

Nitrogen dioxide (NO_2) may present an exposure problem to Army personnel involved in some types of ammunition handling operations. Detectable exposures to nitrogen dioxide ranged between 2 and 77 percent of the OSHA-PEL during ammunition handling activities. The largest exposure occurred during a warehousing operation using the Baker-Deutz engine in an Igloo-type magazine (Table 9; test 12). Although this exposure level was only 77 percent of the OSHA-PEL, it exceeded the ACGIH-TLV for nitrogen dioxide.

Continuous monitoring for "oxides of nitrogen" indicates that the mean indoor air quality during unloading activities could reach levels equal to 40 percent of the OSHA-PEL for NO_2, and confirms that the "oxides of nitrogen" problem is most severe during warehousing operations. Although these test results indicate the potential for a serious health risk, the results of the continuous monitoring cannot be compared directly with the OSHA-PEL or ACGIH-TLV for nitrogen dioxide because the instrument reports data as total oxides of nitrogen (which include both NO and NO_2). Although the NO_2 contribution to the total oxides of

Army personnel to sulfur based irritants and sulfuric acid. As in the case of TSP, exposure to these aerosols during the operation of diesel-powered forklifts should not present a health problem. Even if both the sulfates and sulfites collected were assumed to produce a synergistic effect similar to aerosols of sulfuric acid, the worst case exposures to this aerosol would be less than 50 percent of the OSHA-PEL and ACGIH-TLV. The worst case (0.58 mg/m^3 of sulfate) was during a warehousing operation in a Stradley-type magazine using the Baker-Deutz vehicle (Table 5; test 30).

Nitric Oxide

Nitric oxide (NO) emissions may present exposure problems under some operating scenarios. During one test the Baker-Deutz vehicle, performing warehousing operations in a Igloo-type magazine, created a potential exposure (26.62 mg/m^3) in excess of the OSHA-PEL and ACGIH-TLV (Table 9; test 12). This was the only instance when the nitric oxide exposure limit was exceeded; however, exposures in excess of the 50 percent of OSHA-PEL occurred on three other occasions:

1) The Baker-Deutz vehicle in an Igloo-type magazine during a warehousing operation (Table 9; test 28)

2) The Hyster-Perkins vehicle in an Igloo-type magazine during a warehousing operation (Table 9; test 15)

3) The Baker-Deutz vehicle in a Stradley-type magazine during a warehousing operation (Table 5; test 18)

Continuous monitoring of the magazines for NO indicates that the

TABLE 15. EXPOSURE LIMITS FOR DIESEL EXHAUST COMPONENTS

Exhaust component	OSHA PEL,[a] 8-h	ACGIH[b] TWA 8-h	ACGIH[b] STEL 15-min
Particulate components			
Insoluble fraction			
Total nuisance dust	15 mg/m^3	10 mg/m^3	-
Soluble fraction			
Polycyclic aromatic hydrocarbon (coal tar tar pitch volatiles)	0.2 mg/m^3	0.2 mg/m^3	-
Gaseous components			
Carbon monoxide	50 ppm (55 mg/m^3)	50 ppm (55 mg/m^3)	400 ppm (440 mg/m^3)
Nitric oxide	25 ppm (30 mg/m^3)	25 ppm (30 mg/m^3)	35 ppm (45 mg/m^3)
Nitrogen dioxide	5 ppm (10 mg/m^3)	3 ppm (6 mg/m^3)	5 ppm (10 mg/m^3)
Sulfur dioxide	5 ppm (10 mg/m^3)	2 ppm (5 mg/m^3)	5 ppm (10 mg/m^3)
Sulfuric acid	1 mg/m^3	1 mg/m^3	-
Other components			
Odorants	-		-

[a] General Industry Safety and Health Standards - Toxic and Hazardous Substances. Code of Federal Pegulations, Title 29, Chapter XVII, Part 1910, Subpart 2. 47 FR 51117. November 1982 (Ref. 3).

[b] TLV's - Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84. ACGIH. Cincinnati, Ohio (Ref. 4).

on the public health community's current knowledge of the effect of toxic substances on the workforce. The OSHA PEL's are different from the ACGIH TLV's in that, with a few exceptions, they represent the TLV's as interpreted in 1968. These 1968 TLV's were adopted by OSHA during the establishment of the Occupational Safety and Health Act of 1970. Table 15 summarizes the applicable exposure limits.

Based on the results of breathing zone monitoring conducted during the operations, the following conclusions can be drawn as to the health risks posed by each of the exhaust components monitored.

Particulates

The particulate exposures experienced by forklift drivers do not present a problem when interpreted as a nuisance dust. Under the worst conditions, the particulate exposures calculated as TWA's in Tables 4, 5, 7, and 9 only begin to approach 40 percent of the OSHA-PEL and 50 percent of the ACGIH-TLV. The highest particulate concentration was 4.96 mg/m^3 experienced during a warehousing operation in a Stradley-type magazine using the Baker-Deutz vehicle (Table 5; test number 14).

Exposures to the PAH's were below the detection limits of the sampling and analytical methods (3.3 ng/m^3). Based on these results PAH can be expected to be at concentrations less than 1 percent of the OSHA-PEL and ACGIH-TLV.

Sulfates and Sulfites

The concentrations of sulfates (SO_4^{-2}) and sulfite (SO_3^{-2}) were measured to obtain an estimate of the possible exposure of study.[1] These conclusions were that the continuous monitoring results of the two operations are separate and distinct, and the average exhaust emission concentrations from warehousing operations are higher than those from loading/unloading operations. The data collected during the Phase II testing indicate that warehousing activities tend to result in a larger accumulation of exhaust emissions in the magazines than those during loading/unloading, attributable to the fact that during warehousing operations, the vehicles remain inside the magazine during the entire operation. The result is that the concentrations of exhaust emissions rise quickly and are sustained at higher levels than during the loading/unloading operations. Because the continuous monitoring results are reflective of "area" concentrations" rather than "personal exposures", a direct comparison with established exposure limits cannot be made.

COMPARISON OF PERSONNEL EXPOSURES AND MAGAZINE AIR QUALITY WITH OSHA PERMISSIBLE EXPOSURE LIMITS

Two sources of information are available for use in judging the health risks associated with exposure to the diesel forklift exhausts: OSHA's permissible exposure limits (PEL's) and the ACGIH's threshold limit values (TLV's). Emphasis is placed on a comparison of the test results with the OSHA-PEL's because these limits represent Federal health standards for the workplace. The ACGIH TLV's are also of interest; although these limits are not binding regulations, they do represent what can be considered "good-practice" guidelines. The TLV's are exposure limits based

IV. CONCLUSIONS

The Phase II test results led to the following conclusions regarding the impact of diesel exhaust on magazine air quality:

1) The impact of diesel exhaust on breathing zone exposures and magazine air quality depends largely on the type of operation being performed and the type of magazine being used. Of the two operating scenarios investigated (i.e., loading/unloading and warehousing), warehousing presents the greater potential risk to the health and safety of Army personnel. Of the two magazines investigated (i.e., Stradley and Igloo-types) only the Igloo-type structures of the size encountered in this study are likely to contribute to a hazardous situation.

2) Breathing zone exposures and magazine air quality data were compared with the OSHA permissible exposure levels and ACGIH threshold limit values. Under the operating conditions, ventilation, and temperatures experienced during the test, nitrogen dioxide, nitric oxide and carbon monoxide may pose a health risk to Army personnel in small structures similar in size and design to the Igloo-type magazines study.

3) A performance hierarchy can be suggested from the results of the air monitoring data. The Still-Deutz and Hyster-Isuzu vehicles appear to have out performed the Hyster-Perkins and Baker-Deutz forklifts. Under the conditions tested the Still-Deutz and Hyster-Isuzu did not exceed any of the OSHA permissible exposure limits for the exhaust components measured.

CHARACTERIZATION OF DIESEL FORKLIFT IMPACT ON MAGAZINE AIR QUALITY

Indoor air quality was monitored during both loading/unloading and warehousing operations with each of the four vehicles. The Phase II results substantiate the conclusions of the Phase I

TABLE 14. CONTINUOUS AIR MONITORING DATA COLLECTED DURING WAREHOUSING OPERATIONS IN IGLOO-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Test duration, min.	Sulfur dioxide, ppb	Carbon monoxide, ppm	Nitric oxide, ppb	Total oxides of nitrogen, ppb	Air flow, cfm
Hyster-Isuzu (number 2)	5	110	a	a	7940	9490	a
	7	100	a	a	4890	5830	a
	22	90	a	a	4390	5220	a
	27*	120	a	a	6180	7130	a
Hyster-Perkins (number 3)	3	50	a	a	13450	14750	a
	15	90	a	a	10830	9730	a
Baker-Deutz (number 4)	12	170	a	a	12630	14110	a
	28*	40	a	a	10270	10910	a

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Parameter was not monitored during test.

TABLE 13. CONTINUOUS AIR MONITORING DATA COLLECTED DURING LOADING/UNLOADING OPERATIONS IN IGLOO-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Test duration, min.	Sulfur dioxide, ppb	Carbon monoxide, ppm	Nitric oxide, ppb	Total oxides of nitrogen, ppb	Air flow, cfm
Hyster-Isuzu (number 2)	20	110	a	a	5050	5710	a
	21	110	a	a	3960	4730	a
Hyster-Perkins (number 3)	16	90	a	a	4390	5220	a
	17	100	a	a	5400	5870	a
Baker-Deutz (number 4)	23	100	a	a	10010	11040	a
	24	130	a	a	8730	9370	a

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Parameter was not monitored during test.

TABLE 12. CONTINUOUS AIR MONITORING DATA COLLECTED DURING WAREHOUSING OPERATIONS IN STRADLEY-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Test duration, min.	Sulfur dioxide, ppb	Carbon monoxide, ppm	Nitric oxide, ppb	Total oxides of nitrogen, ppb	Air flow, cfm
Hyster-Isuzu (number 2)	6	185	618	2.8	2161	2580	562
	8	235	801	2.0	3161	3735	492
	9	170	810	1.7	3027	3602	683
	10	170	847	3.0	3862	4610	397
	11	175	923	2.8	3523	4214	409
	13	220	708	3.2	3560	4311	426
	14	185	714	2.3	2764	3288	464
	29*	170	1349	3.9	4018	4712	341
Hyster-Perkins (number 3)	8	240	722	3.4	4462	5154	500
	9	170	752	3.9	4210	4945	637
	10	175	1111	7.9	7148	8002	380
	11	180	922	6.7	5823	6780	465
	18	130	827	6.5	5050	5754	409
	26	65	1102	9.3	7492	8352	296
Baker-Deutz (number 4)	13	215	1156	4.7	9448	9793	419
	14	180	998	4.3	9434	10199	509
	18	195	1295	3.8	11711	12779	395
	19	175	940	3.7	9594	10433	478
	25*	130	964	2.7	6574	7016	426
	30*	185	1663	3.5	9868	10713	253

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

continuous monitoring data collected during loading/unloading operations in Stradley-type magazines. Table 12 summarizes the continuous monitoring data collected during warehousing operations in Stradley-type magazines. Continuous monitoring in Igloo-type magazines was limited to NO and NO_x. Tables 13 and 14 present summaries of the continuous monitoring data collected in Igloo-type magazines during loading/unloading and warehousing operations, respectively.

TABLE 11. CONTINUOUS AIR MONITORING DATA COLLECTED DURING LOADING/UNLOADING OPERATIONS IN STRADLEY-TYPE MAGAZINES

Vehicle type, body-engine	Test number	Test duration, min.	Sulfur dioxide, ppb	Carbon monoxide, ppm	Nitric oxide, ppb	Total oxides of nitrogen, ppb	Air flow, cfm
Still-Deutz (number 1)	1*	465	469	2.6	1243	1359	a
	2*	505	508	2.8	1511	1647	a
	4	515	205	0.8	1828	1984	458
Hyster-Isuzu (number 2)	1*	455	349	3.1	1003	1200	a
	2*	515	709	4.0	1671	1933	a
Hyster-Perkins (number 3)	4	505	546	4.3	3562	4240	466

*Indicates that the test vehicle was operating on high sulfur fuel (see Appendix C).

[a]Air flow data was not collected during this test because of instrument malfunction.

Six exhaust components are reported in Table 9: TSP, SO_4^{-2}, SO_3^{-2}, NO, NO_2 and CO. The carbon monoxide exposures are summarized in Table 10 by time-weighted average, highest 15-minute concentration, and instantaneous peak concentrations. PAH and odorants were not captured in sufficient amounts for detection by the analytical methods used.

During most of the testing the Army utilized two drivers for each vehicle, resulting in each driver being exposed to diesel emission for a duration equal to approximately half a given test period.*

CONTINUOUS AIR MONITORING

Continuous air monitoring was conducted during both the loading/unloading and warehousing operations. The results were compiled for both operations for each of the vehicles tested and presented in tabular format. The test duration and mean test concentrations are reported for each exhaust component by test vehicle.

Monitoring in Stradley-Type Magazines

Continuous monitoring was conducted in Stradley-type magazines for: sulfur dioxide (SO_2), carbon monoxide (CO), nitric oxide (NO), total oxides of nitrogen (NO_x) and volumetric air flow (as measured through the magazine's passive ventilating system) in cubic feet per minute (cfm). Table 11 summarizes the

*This action was taken as an administrative precaution to avoid exposing the drivers to emissions from a full test period.

to a transmission malfunction (vehicle number 1) during Phase II testing (only three loading and three unloading tests were conducted in Stradley-type magazine), it remained the "cleanest" of the test vehicles. Warehousing and loading/unloading tests on the remaining three vehicles also suggest a possible performance hierarchy. In almost every instance the Hyster-Isuzu (vehicle number 2) was cleaner than either the Hyster-Perkins (vehicle number 3) or the Baker-Deutz (vehicle number 4). The Hyster-Isuzu (vehicle number 2) consistantly outperformed the Baker-Deutz (vehicle number 4) vehicle in every exhaust component category. In many cases, the airborne concentrations inside the magazine during Hyster-Isuzu operations was 50 percent of the concentrations generated by the Baker-Deutz vehicle. A similar relationship was found between the Hyster-Isuzu and the Hyster-Perkins (vehicle number 3) for SO_2 and CO. The Hyster-Perkins appears to perform similarly to the Hyster-Isuzu in emission of NO and NO_x.

The results from the Phase II testing provide an additional base of data from which to judge the operation of diesel-powered forklifts during ammunition handling and storage activities in Stradley and Igloo-type magazines. The Phase II results suggest that the relative performance of at least three of the test vehicles can be established (very limited data was collected on the Still-Deutz vehicle). When considering the results of the Phase II investigation, a hierarchy of performance can be established begining with the best (cleanest) performance:

- Still-Deutz (Vehicle 1)

- Hyster-Isuzu (Vehicle 2)
- Hyster-Perkins (Vehicle 3)
- Baker-Deutz (Vehicle 4)*

The absolute safety of the vehicles will likely depend on the use and operating conditions of the forklifts at any given time; however, it is believed that under a majority of work conditions likely to be encountered, a similar hierarchy will result.

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* Consideration of this hierarchy must be tempered by the knowledge that the Army suspected that the Baker-Deutz engine was seriously malfunctioning during the course of the Phase II testing. The nature and extent of this malfunction was not known at the time this report was written. The Baker-Deutz vehicle would be expected to produce emission levels similar to the Still-Deutz vehicle since the same model Deutz engine is utilized in both.

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APPENDIX A

SAMPLING PROCEDURES AND ANALYTICAL METHODS

CONTENTS

NITROGEN DIOXIDE AND NITRIC OXIDE IN AIR

Measurements Support Branch

Analytical Method

Analyte: Nitrogen Dioxide and Nitric Oxide	**Method No.:** P&CAM 231
Matrix: Air	**Range:** 0.8 to 30 ppm of NO_2 or NO in a 1-liter sample
Procedure: Solid sorbent collection; triethanolamine extraction; spectrophotometry	**Precision(CV_T):** NO_2, 0.07 at 0.5 to 5 ppm; NO, 0.06 at 12.5 to 50 ppm
Date Issued: 6/30/76	**Classification:** D (Operational)
Date Revised:	

1. **Principle of the Method**

Nitrogen dioxide (NO_2) and nitric oxide (NO) are collected from air in a three-section sorbent tube. The NO_2 is absorbed in the first section, which contains triethanolamine (TEA) impregnated on molecular sieve. The NO is converted to NO_2 by a proprietary oxidizer in the second section. The NO_2 thus formed from the NO is absorbed in the third section by another bed of TEA-impregnated molecular sieve. The first and third sections are desorbed with solutions of TEA in water and the nitrite in these solutions is determined spectrophotometrically by the Griess-Saltzman reaction. (Reference 11.1). The nitrite found in the first section is reported as NO_2 and the nitrite in the third section is reported as NO.

2. **Range and Sensitivity**

2.1 The linear range of the standard curve is from 0.5 to 18 μg of nitrite in 10 mℓ of desorbing solution, which corresponds in this method to a range of 0.8 to 30 ppm of NO_2 or NO in a 1-liter sample of air.

2.2 The sensitivity is 0.4 μg/10 mℓ for an absorbance of 0.04.

2.3 The upper limit of the range can be extended by taking smaller aliquots for analysis, or be diluting intensely colored solutions with water.

3. **Interferences**

3.1 Inorganic nitrites cause positive interference.

3.2 Nitric acid and nitrates do not interfere.

3.3 Ammonia does not interfere.

4. **Precision and Accuracy**

4.1 The average recovery for 22 samples in the range 0.5 to 5 ppm of NO_2 was greater than 96% and the coefficient of variation was 0.07.

4.2 For 18 samples the average recovery of NO varied with the amount of NO collected. The recovery was 100% at 12.5 ppm. At 25 ppm only 84% recovery was achieved, and at 50 ppm only 67%. However, the coefficient of variation over the range was only 0.06. The recovery may vary depending upon the sample flow rate and the properties of the particular lot of oxidizer used. Each laboratory should determine the efficiency of the sampling tubes employed.

4.3 The accuracy of the overall sampling and analytical method has not been determined.

5. **Advantages and Disadvantages of the Method**

5.1 Both nitrogen dioxide and nitric oxide are collected simultaneously.

5.2 This method is simple and convenient for field sampling.

5.3 Samples can be stored at ambient temperature for at least 10 days without any effect on the results.

5.4 At 50 ppm of NO the collection efficiency is poor (about 67%) because the oxidizer is consumed.

5.5 If high humidity or water mist is present, the breakthrough volume can be severely reduced. If water condenses in the tube, NO_2 and NO may not be collected quantitatively.

6. **Apparatus**

6.1 **Sampling Equipment**

6.1.1 Solid sorbent tubes are made in the following manner. Using a gas-oxygen torch, heat a section of 5-mm i.d., 7-mm o.d. Pyrex glass tubing and pull it apart to form a tube approximately 15 cm long with a taper 2 cm long. Seal the tapered end of the tube in the flame. Allow it to cool, then insert a small plug of glass wool through the open end of the tube; push the glass wool through the open end of the tube with a thin wooden stick and pack gently. Weigh 400 mg of TEA sorbent and pour the material into the tube. (See Section 7.2) Gently tap the tube on the table top several times to ensure uniform packing. Insert another small plug of glass wool to keep the TEA sorbent in place. For the next section, pour 800 mg of oxidizer into the tube. (See Section 7.1.) Again tap the tube and insert a plug of glass wool; pack lightly. Insert another plug of glass wool, maintaining an air gap of 12 mm between these two plugs. Weigh 400 mg of TEA sorbent and pour the material into the tube. Carefully tap the tube and gently pack another glass wool plug without closing the 12-mm air gap. Seal the open end of the tube with the torch. See the figure on page 231-9.

6.1.2 A personal sampling pump that can provide a flow rate of 50 mℓ/min within 5% accuracy is required. The pump should be calibrated with a representative sorbent tube in the sampling line. A dry or wet test meter or glass rotameter that will determine the flow rate to within 5% may be used for the calibration.

6.2 Spectrophotometer capable of measurements at 540 nm.

6.3 Matched glass cells or cuvettes, 1-cm path length.

6.4 Assorted laboratory glassware: pipettes, glass-stoppered graduated cylinders, and volumetric flasks of appropriate sizes.

7. Reagents

7.1 **Oxidizer**. Proprietary material Number 1900277 from the Drägerwerk Company of West Germany, supplied through its U.S. distributor, National Mine Safety Company, or the equivalent.

7.2 **TEA Sorbent**. Place 25 g of triethanolamine in a 250-mℓ beaker, add 4 g of glycerol, 50 mℓ of acetone and sufficient distilled water to bring the volume up to 100 mℓ. To the mixture add about 50 mℓ of Type 13X, 30/40-mesh Molecular Sieve. Stir and let stand in a covered beaker for about 30 min. Decant the excess liquid, and transfer the molecular sieve to a porcelain pan. Place the pan under a heating lamp until most of the moisture has evaporated. Complete the drying in an oven at 110°C for 1 hr. The sorbent should be free flowing. Store it in a closed glass container.

7.3 **Desorbing Solution**. Dissolve 15.0 g of triethanolamine in approximately 500 mℓ of distilled water, add 0.5 mℓ of *n*-butanol, and dilute to 1 liter.

7.4 **Hydrogen Peroxide, 0.02%(v/v)**. Dilute 0.2 mℓ of 30% hydrogen peroxide to 250 mℓ with distilled water.

7.5 **Sulfanilamide Solution**. Dissolve 10 g of sulfanilamide in 400 mℓ of distilled water. Add 25 mℓ of concentrated phosphoric acid, mix well, and dilute to 500 mℓ.

7.6 **NEDA Solution**. Dissolve 0.5 gm of N-(1-naphthyl)ethylenediamine dihydrochloride in 500 mℓ of distilled water.

7.7 **Nitrite Stock Standard Solution (100 μg/mℓ)**. Dissolve 0.1500 g of reagent grade sodium nitrite in distilled water and dilute to 1 liter.

8. Procedure

8.1 **Cleaning of Equipment**. Wash all glassware with detergent solution, soak in nitric acid, rinse in tap water and distilled water, and then rinse thoroughly with double distilled water.

8.2 **Collection and Shipping of Samples**

8.2.1 Before sampling, break open the ends of the sorbent tube to provide an opening that is approximately one-half the internal diameter of the tube.

8.2.2 The air must flow through the 12-mm air space before it flows through the oxidizer. Therefore attach the end of the tube without the air gap between the oxidizer section and TEA sorbent section to the pump with a length of small diameter Tygon® tubing.

8.2.3 Mount the tube in a vertical position to avoid channeling.

8.2.4 The air being sampled should not pass through any hose or tubing before it enters the sorbent tube.

8.2.5 Turn on the pump to begin sample collection. Sample at a flow rate of 50 mℓ/min or less to obtain a maximum sample volume of 1 liter. Measure the flow rate and time, or volume, as accurately as possible. If a low flow rate pump is used, set the rate to an approximate value and record the initial and final stroke counter readings. Obtain the sample volume by multiplying the number of strokes by the stroke volume.

8.2.6 Measure and record the temperature and pressure of the atmosphere being sampled.

8.2.7 Cap the sorbent tubes with 7-mm i.d. plastic caps immediately after sampling. (Masking tape can be substituted for the plastic caps.)

8.2.8 With each batch of samples, submit one blank sorbent tube. This tube is handled in the same manner as the other tubes (break, seal, and transport) except that no air is drawn through it. When more than ten samples are submitted, include an additional blank for every ten samples.

8.2.9 Pack the capped sorbent tubes tightly and pad them to minimize breakage during shipping.

8.3 Analysis of Samples

8.3.1 With tweezers remove and discard the glass wool plugs from an exposed sorbent tube and transfer each TEA sorbent bed to separate, 25-mℓ glass-stoppered graduated cylinders. Label the graduated cylinder as to the location of the TEA sorbent with respect to the oxidizer section.

8.3.2 To each graduated cylinder add enough of the desorbing solution to make the volume up to 20 mℓ, and shake the mixture vigorously for about 30 sec.

8.3.3 Allow a few minutes for the solids to settle, and then transfer 10 mℓ to another 25-mℓ glass-stoppered graduated cylinder.

8.3.4 Develop the color of the solution for 10 min in the same manner as described for the preparation of the standard curve (Sections 9.4 to 9.6). From the standard curve determine the amount of nitrite in the 10-mℓ aliquot.

8.4 Determination of Collection and Desorption Efficiencies

8.4.1 **Importance of Determination.** The collection and desorption efficiencies of a given compound can vary from one laboratory to another and also from one batch of sorbent tubes to another. Thus, it is necessary to determine at least once the percentages of sample collected and then removed in the desorption process. Results indicate that the recovery of NO varies with the amount of NO collected, particularly at higher concentrations (for example, at 50 ppm).

8.4.2 **Procedure for Determining Collection and Desorption Efficiencies.** Sorbent tubes from the same batch as that used in obtaining samples are used in this determination. Known volumes of NO_2 and NO are injected into a bag containing a known volume of air. The bag is made of Tedlar (or another material that will not absorb NO_2 or NO) and should have a gas sampling valve and a septum injection port. The concentrations of NO_2 and NO in the bag may be calculated at room temperature and pressure. A measured volume is then sampled through a sorbent tube with a calibrated sampling pump. At least five tubes are prepared in this manner. These tubes are desorbed and analyzed in the same manner as the samples (Section 8.3).

8.4.3 **Calculation of Desorption Efficiency.** The desorption efficiency (D.E.) is the average concentration (corrected for the blank) of NO_2 or NO found by analysis of the sorbent tubes divided by the concentration of NO_2 or NO in the bag.

9 Calibration and Standards

9.1 Dilute 2 mℓ of the nitrite stock standard (100 μg/mℓ) to 100 mℓ with the desorbing solution to prepare a solution with a nitrite concentration of 2 μg/mℓ.

9.2 To a series of 25-mℓ glass-stoppered graduated cylinders add 1, 3, 5, 7, and 9 mℓ of the dilute standard solution.

9.3 Add enough of the absorbing solution to bring the volume in each cylinder up to 10 mℓ to prepare working standards with nitrite concentrations of 2, 6, 10, 14, and 18 μg/10 mℓ.

9.4 To each graduated cylinder, add 1 mℓ of the 0.02% hydrogen peroxide solution, 10 mℓ of the sulfanilamide solution, and 1.4 mℓ of the NEDA solution, with thorough mixing after the addition of each reagent.

9.5 Allow 10 min for complete color development.

9.6 Measure the absorbance of the solutions at 540 nm, using a reagent blank in the reference cell.

9.7 Prepare a standard curve by plotting absorbance *versus* weight of nitrite (in μg) in 10 mℓ of the desorbing solution.

10. Calculations

10.1 From the standard curve, read the weight of nitrite (in μg) in 10 mℓ of the desorbing solution corresponding to the absorbance of the sample solution. Multiply this weight by 2 to determine the total amount (in μg) of nitrite extracted with 20 mℓ of desorbing solution from the sorbent section being analyzed. The calibration procedure is based upon the empirical observation that 0.63 mole of sodium nitrite produces the same absorbance in the color-developed solution as 1 mole of NO_2. (See Reference 11.2.) Divide the amount of nitrite desorbed from the sorbent material by 0.63 to determine the apparent amount of NO_2 collected in the sorbent section. These calculations are summarized in the following equation:

$$W = \frac{\mu g\ NO_2^- \times 2}{0.63}$$

where: W = weight (in μg) of NO_2 found.

10.2 Correct the amount of NO_2 calculated in Section 10.1 for the amount of NO_2, if any, found on the corresponding sorbent section of a blank tube to obtain the amount of NO_2 in the sample, as follows:

$$W_s = W - W_b$$

where W_s = corrected weight (in μg) of NO_2 in sample.

W_b = weight (in μg) of NO_2 in the corresponding section of a blank tube.

10.3 The concentration of NO_2 in parts per million (ppm) by volume in the air sample is calculated as follows:

$$ppm = \frac{W_s}{V} \times \frac{24.45}{M.W.} \times \frac{760}{P} \times \frac{T+273}{298}$$

where V = volume (liters) of air sampled.
M.W. = molecular weight.
24.45 = molar volume (liter/mole) at 25°C and 760 mmHg
P = pressure (mmHg) of air sampled
T = temperature (C°) of air sampled

10.4 The ppm of NO_2 found in the third section (downstream from the oxidizer) is reported as ppm of NO

11. References

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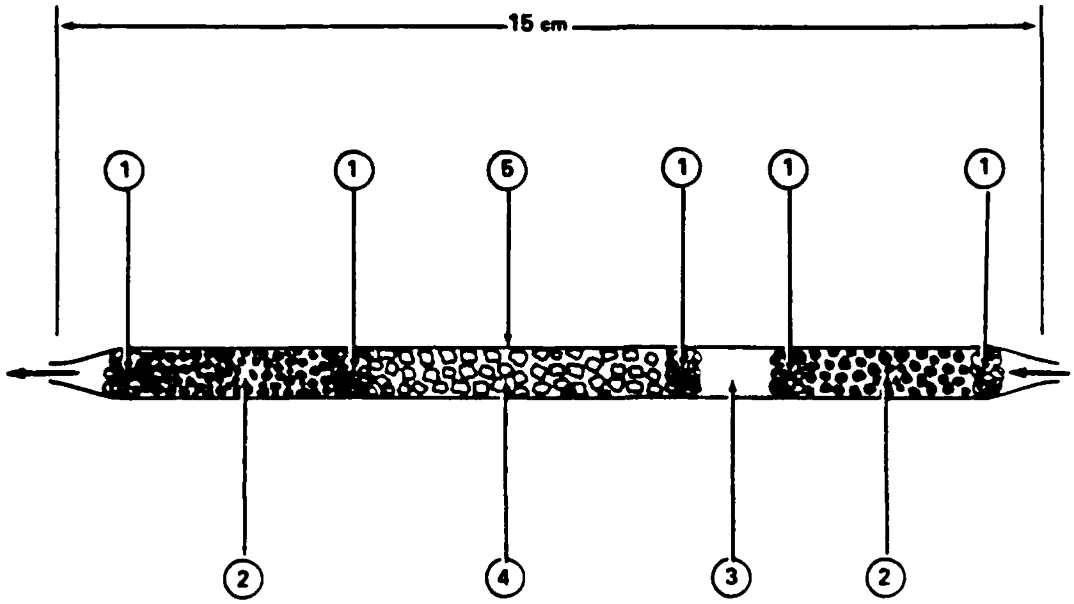

1. GLASS WOOL PLUGS
2. TEA SORBENT, 400 mg
3. AIR GAP, 12 mm
4. OXIDIZER, 800 mg
5. GLASS TUBE, 5 mm i.d.

SORBENT TUBE FOR NO_2 and NO

5. Advantages and Disadvantages of the Method

5.1 The extraction is done at room temperature. Complete extraction of the TpAH is assured by the fine shredding of the glass fibers and the breaking up of clumps of particulates.

5.2 Only a relatively small sample of air particulates is required. Complete analysis time is well under an hour, most of which is waiting time.

5.3 Most of the polar constituents are removed by adsorption in the homogenizing vessel. The remainder are removed by the fast simple chromatographic analysis.

5.4 The method can accommodate a wide range of hydrocarbon pollution concentrations, since sample extract volumes ranging from 0.1 to 2 ml can be chromatographed.

5.5 Time and work are saved by not weighing the particulates or soluble organics.

TABLE 2

Elution of Fluorene, Analogues and Derivatives

Compound	t, Min.	% Eluted Through Column	PA/$\mu g \times 10^{-3}$
Fluorene	2.0	100	2.9
Dibenzothiophene	2.0	96	1.8
Dibenzofuran	2.0	98	0.3
Fluoranthene	2.0	95	2.5
Benzo(k)fluoranthene	1.8	97	1.4
Benzo(b)fluoranthene	1.0	99	1.6
2-Ethylfluorene	1.0	95	1.6
11H-Benzo(b)fluorene	1.0	110	5.6
2-Nitrofluorene	4.8	104	0.2
2,5-Dinitrofluorene	7.0	71	0.3
9-Fluorenol	8.5	14	0.2
3,6-Dinitrodibenzoselenophene	18.2	38	0.2
3-Aminofluorene	18.2	68	0.4
4-Fluorenecarboxylic acid		Retained on column	
2-Hydroxyfluorene		Retained on column	
2-Nitro-7-hydroxyfluorene		Retained on column	
Fluorenone		Retained on column	

TABLE 3

Elution of Polychloro Derivatives of Di- and Tricyclic Hydrocarbons[a]

Compound	% Eluted Through Column	PA/$\mu g \times 10^{-3}$
1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane (p,p'DDD)	94	0.02
1,1-Dichloro-2,2-bis(p-chlorophenyl)ethylene (DDE)	97	0.50
1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane (p,p'DDT)	85	0.02
Aroclor 1260 (chlorinated biphenyls, 60% chlorine)	100	0.13
Aroclor 5432 (chlorinated triphenyls, 32% chlorine)	104	0.61
Halowax 1099 (mixture of tri- and tetrachloro naphthalenes, 52% chlorine)	101	0.25
1,2,3,4,5,6,7,8-Octachloronaphthalene	97	0.64
2,3,4,5,6,2',3',4',5',6'-Decachlorobiphenyl	95	0.19
1,2,3,4,5,6,7,8-Octachlorodibenzofuran	93	0.33
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	98	0.85
Tetradecachloro-p-terphenyl	95	0.22

[a]Retention times from 1 to 2 min.

3.4 Oxygenated compounds, some phenols and aza and imino-heterocyclics (except some members of the indole series) are retained. Examples are benzoquinone, o-ethylphenol, acridine, and quinoline.

3.5 Most interfering compounds have quite low peak area/μg values, which decreases their significance, as shown in Tables 2, 3, and 4.

TABLE 1

Elution of PAH[a]

Compound	% Eluted Through Column	PA[c]/μg $\times 10^{-6}$
Mono-, dicyclics		
Benzene	99	0.4
N-Hexylbenzene	100	0.5
N-Heptylbenzene	100	0.7
Naphthalene	101	0.7
Azulene	93	3.0
Tricyclics		
Anthracene	100	36.0
9-Methylanthracene	99	15.0
Xanthene	102	1.3
Phenoxathiin	92	0.2
Phenanthrene	100	10.0
Tetracyclics		
Naphthacene	95	4.7
Chrysene	105	4.5
Pyrene	96	3.6
4-Methylpyrene	100	1.7
1,3-Dimethylpyrene	96	0.9
Triphenylene	100	9.0
Benz(a)anthracene	96	4.3
7,12-Dimethylbenz(a)anthracene	102	3.3
Pentacyclics		
Dibenz(a,h)anthracene	96	0.6
Benzo(a)pyrene	100	5.3
Benzo(e)pyrene	92	2.2
Picene	99	5.0
Perylene	96	5.8
Hexacyclics		
Benzo(ghi)perylene	99	1.8
Anthanthrene	93	2.6
Dibenzo(fg, op)naphthacene	93	0.6
Coronene	91	0.5
Dibenzo(g,p)chrysene	96	1.0
Naphtho(2,1,8-qra) naphthacene[b]	100	0.7

[a]Retention time is approximately 2 minutes. [b]Or naphtho(2,3-a)pyrene. PA = Peak Area.

4. Precision and Accuracy

4.1 Homogeneous glass fiber samples containing air particulates were analyzed by Soxhlet and ultrasonic extraction. See Table 5. The relative standard deviation for 6 ultrasonic extracts was ± 1.33% and for 4 Soxhlet extracts ± 26.1%. The ratio of ultrasonic to Soxhlet recovery was 1.14.

4.2 Recovery of PAH added to glass fiber filter blanks and extracted ultrasonically was 95% for anthracene; 97.5% for phenanthrene; and 98.2% for benzo(a)pyrene (Table 6).

TOTAL PARTICULATE AROMATIC HYDROCARBONS (TpAH) IN AIR

Physical and Chemical Analysis Branch

Analytical Method

Analyte:	TpAH	**Method No.:**	P&CAM 206
Matrix:	Air	**Range:**	Lower limit, 3 nanograms benzo(a)pyrene
Procedure:	Sampling with glass fiber filter, extract ultrasonically, enrich and measure with HPLC	**Precision:**	± 1.33% RSD (Analytical)
Date Issued:	1/1/75	**Classification:**	E (Proposed)
Date Revised:			

1. **Principle of the Method**

Airborne particles collected from polluted atmospheres on glass fiber filters are extracted ultrasonically in the presence of silica powder (11.1-3). The TpAH in the filtered extract are separated by high speed liquid chromatography on a column of Corasil II with a non-polar solvent, and the absorbance is measured by a UV detector at 254 nm. Compounds responding to the detector are shown in Tables 1, 2, 3, and 4. The extract is suitable also for the analysis of the aliphatic hydrocarbons (11.4).

2. **Range and Sensitivity**

2.1 Minimum reproducible level of standard benzo(a)pyrene at 254 nm is approximately 3 nanograms.

2.2 The minimum detectable TpAH (in terms of benzo(a)pyrene) for particulates collected on one glass fiber filter of approximately 452 cm^2 is approximately 5 micrograms, or 3.3 nanograms m^3 of air if 1500 m^3 of air are sampled in the ambient atmosphere.

2.3 The upper range of TpAH concentrations can be increased by dilution of the extract and/or analyzing smaller samples. Sensitivity for low concentrations can be increased by injecting larger samples into the chromatograph. Thus, very high levels of TpAH can be measured.

3. **Interferences**

3.1 Any compound which is not retained on the silica column and absorbs light at 254 nm is measured in this procedure.

Fluorene and some of its analogues and derivatives listed in Table 2, and polychloro derivatives of some di- and tricyclic hydrocarbons in Table 3 are examples of such compounds.

3.2 Amino, carbonyl, hydroxy and nitro compounds elute after the PAH, so do not interfere. See Table 2.

3.3 Carbazoles and aldehydes are either retained or have retention times larger than the PAH, except N-alkyl substituted derivatives, which elute with the PAH. See Table 4.

10.2 Calculate the concentrations in the air sample using the formulae:

$$\text{Total particulate sulfite (mg/m}^3\text{)} = \frac{C_1 \times 10}{V}$$

$$\text{Total particulate sulfate (mg/m}^3\text{)} = \frac{C_2 \times 10}{V}$$

$$\text{Sulfur dioxide (mg/m}^3\text{)} = \frac{(C_3 \times 10 \times 0.08002) + (C_4 \times 10 \times 0.6669)}{V}$$

$$\text{Sulfur dioxide (ppm)} = 0.3817 \times \text{sulfur dioxide (mg/m}^3\text{)} \times \frac{760 \times T}{298 \times P}$$

where V is the volume (liters) of air sampled.

T is the absolute temperature ($^{o}K = {}^{o}C + 273$) at which the sample was taken.

P is the pressure (mm Hg) at which the sample was taken.

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Inorganic Methods Development Section

- $SO_3^=$ retention time: 6-7.5 min (depending on eluent)

- $SO_4^=$ retention time: 9-10.5 min (depending on eluent)

8.3.4 Measure and record the peak height or peak area of each sulfite and sulfate peak. If interfering substances (e.g., nitrate or phosphate) are present, establish positive identity of sulfite and sulfate peaks by adding known amounts of standard solutions and by changing eluent concentration for better separation, if necessary.

9. Calibration and Standardization

9.1 From the 100 ppm working standards, prepare 5, 10, 15, 20, 30, 50, and 80 ppm sulfate and sulfite standards by diluting, respectively, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, and 8.0 mL to 10 mL with deionized water. These standard solutions should be prepared fresh daily.

9.2 With each set of samples analyzed, a complete calibration curve should be constructed, using the standards prepared in 9.1 or additional standards as needed. Plot peak height or peak area vs. concentration for both sulfite and sulfate. A sulfite standard with nominal concentration C_n (ppm) will give two peaks: a sulfite peak, C, and a sulfate peak, C_s (ppm). The relationship between these is $C = C_n - C_s \times 0.8334$.

10. Calculations

10.1 From the calibration curves obtained in Sec. 9.2, read the concentrations of sulfite and sulfate ions in each sample in ppm. Designate whether the ions originated on the cellulose ester membrane filter or the treated cellulose filter. Thus, four concentrations will be obtained.

C_1 = concentration, ppm, of sulfite from cellulose ester membrane filter

C_2 = concentration, ppm, of sulfate from cellulose ester membrane filter

C_3 = concentration, ppm, of sulfite from treated cellulose filter

C_4 = concentration, ppm, of sulfate from treated cellulose filter

8.2.2 Assemble the filter cassette as follows: First, place a backup pad in place in the rear section of the cassette. On top of this place a treated cellulose filter (Sec. 6.1.4) and then put the center retaining ring of the cassette in place. Next, put another backup pad on top of the retaining ring, place a mixed cellulose ester membrane filter (Sec. 6.1.3) on top of the backup pad, and put the front section of the cassette in place. A shrinkable band should be used to seal the cassette.

8.2.3 Collect the sample at 1.5 liters per minute. The air being sampled should not pass through any hose or tubing before entering the cassette. A sample size of 200 liters is recommended.

8.2.4 If significant amounts of sulfuric acid are suspected in the sample, the cellulose ester membrane filter must be transferred to a clean, glass bottle within 4 hours of sampling to avoid low recovery of sulfate. Handle the filter with tweezers to avoid contamination. Reclose the cassette containing the treated cellulose filter.

8.2.5 Carefully record the sample identity and all pertinent sampling data. With each batch of up to 10 samples submit appropriate blank filters for analysis.

8.3 Analysis of Samples

8.3.1 Put the two filters from the cassette into two separate, clean, screw-top glass bottles. Add 10.0 mL eluent (Sec. 7.14) to each bottle and let stand, with occasional vigorous shaking, for 30 minutes.

8.3.2 Pour the contents of the bottle into a syringe fitted with an in-line filter and collect the filtrate in a second syringe.

8.3.3 Inject the filtered sample onto the chromatograph and record the sample identity and instrumental conditions. Typical operating conditions are:

- sensitivity: 30 μmho full scale (for 5-100 ppm sulfate and sulfite)

- eluent: 0.0030 $\underline{M}$ Na_2CO_3, 0.0030 $\underline{M}$ $NaHCO_3$

- flow rate: 138 mL/hr

- separator column: 3 mm I.D. x 500 mm (anion exchanger), preceded by a precolumn

- suppressor column: 6 mm I.D. x 250 mm (cation exchanger)

7.2 Potassium hydroxide, KOH (pellets)

7.3 Glycerol

7.4 Sodium carbonate, Na_2CO_3

7.5 Sodium bicarbonate, $NaHCO_3$

7.6 Sodium sulfite, Na_2SO_3

7.7 Sodium sulfate, Na_2SO_4

7.8 Nitrogen gas

7.9 Filter impregnating solution. Dissolve 20 g KOH in about 50 mL deionized water, add 10 mL glycerol and dilute with deionized water to 100 mL.

7.10 Sulfite stock standard (1000 ppm $SO_3^=$). Add 5 mL glycerol to a 100 mL volumetric flask and dissolve in approximately 75 mL deionized water which has been heated to 100°C and cooled under nitrogen to remove dissolved oxygen. Add 0.1575 g Na_2SO_3 and dilute to 100 mL with deionized water. This standard should be prepared fresh weekly.

7.11 Sulfite working standard (100 ppm $SO_3^=$). Pipette 10.0 mL of 1000 ppm sulfite stock standard into a 100 ml volumetric flask and dilute to 100 mL with a solution containing 2% (v/v) glycerol. Prepare fresh daily.

7.12 Sulfate stock standard (1000 ppm $SO_4^=$). Dissolve 1.4792 g Na_2SO_4 in deionized water and dilute to 1 liter.

7.13 Sulfate working standard (100 ppm $SO_4^=$). Dilute 10.0 mL of the sulfate stock standard to 100 mL with deionized water.

7.14 Eluent (0.003 $\underline{M}$ $CO_3^=$/0.003 $\underline{M}$ HCO_3^-). Dissolve 1.27 g Na_2CO_3 and 1.01 g $NaHCO_3$ in 4 liters of deionized, filtered water.

8. Procedure

8.1 Cleaning of Equipment. Glassware, including screw cap bottles, should be washed in detergent and rinsed in dilute (1-5%) nitric acid, followed by thorough rinsing with distilled or deionized water.

8.2 Collection and Shipping of Samples

8.2.1 Each personal sampling pump must be calibrated with a representative filter cassette in line to assure accurately known sample volumes.

6. Apparatus

6.1 The apparatus for the collection of personal air samples consists of:

6.1.1 Filter holder, 3-piece cassette, polystyrene, 37-mm diameter.

6.1.2 Shrinkable cellulose band.

6.1.3 Mixed cellulose ester membrane filter, 0.8 micrometer pore size, 37-mm diameter, supported by a cellulose backup pad.

6.1.4 Cellulose filter, Whatman-40 or equivalent, impregnated with potassium hydroxide-glycerine solution, supported by a cellulose backup pad. To prepare the filter, saturate it with filter impregnating solution on a clean glass plate or watch glass and dry at 100°C for 20-30 minutes.

6.1.5 Personal sampling pump whose flow can be calibrated in line with a representative loaded filter holder to an accuracy of ±5% at the recommended flow rate.

6.1.6 Thermometer

6.1.7 Manometer

6.1.8 Stopwatch

6.1.9 Screw cap, glass bottles, such as scintillation vials.

6.1.10 Tweezers

6.2 Ion-exchange chromatograph, equipped with electrical conductivity detector and recorder or integrator.

6.3 10-mL pipette

6.4 10-mL plastic syringe with male Luer fitting

6.5 In-line filter with Luer fitting, 25 mm diam (0.8 μm membrane filter).

6.6 Volumetric flask, 100 mL

7. Reagents

All reagents used should be ACS Reagent Grade or better.

7.1 Deionized, filtered water. Conductivity-grade deionized water with a specific conductance of 10 μmho/cm or less is needed for preparation of eluents and other solutions which will be used on the ion chromatograph. The water should be filtered through a membrane filter (0.45-0.8 μm pore size) before use to avoid plugging valves on the chromatograph.

2. Working Range, Sensitivity, and Detection Limit

2.1 The working range for a 200-L air sample is 0.1-10 mg $SO_4^=$ or $SO_3^=/m^3$, and 0.04-4 ppm SO_2 (0.1-10 mg SO_2/m^3). This corresponds to 20-2000 μg of sulfate, sulfite or sulfur dioxide per sample.

2.2 The sensitivity at 30 μmho full scale is 5 μg sulfate, sulfite, or sulfur dioxide per sample per mm chart deflection. The sensitivity may be improved by using scale expansion on the readout and by using a smaller volume than 10 mL to desorb the sample.

2.3 The detection limit is approximately 0.5 μg $SO_4^=$ or $SO_3^=$/mL in the solution injected, corresponding to 5 g sulfate, sulfite, or sulfur dioxide per sample.

3. Interferences

3.1 Oxidation of particulate sulfite on the sample filters results in a positive bias for sulfates and a negative bias for particulate sulfites.

3.2 Sulfur trioxide gas, if present in dry atmospheres, gives a positive bias in the sulfur dioxide determination.

3.3 Nitrate or phosphate ions may give similar retention times to sulfite. Identity of the sulfite peak may be established by spiking the samples with known amounts of sulfite and analyzing with at least two different eluents (e.g., the eluent in Section 7.14 and 0.003 M $NaCO_3$/0.001 M $NaHCO_3$).

3.4 Insoluble sulfates collected on the first filter will not be measured unless special care is taken to dissolve them.

4. Precision and Accuracy

4.1 The relative standard deviation of the analytical method is 5% or less in the range 50-1000 μg $SO_3^=$ or $SO_4^=$ per sample, corresponding to 0.25-5 mg/m^3 SO_2, sulfites, or sulfates.

4.2 A major factor affecting accuracy is the tendency of particulate sulfites and absorbed sulfur dioxide to oxidize. Because of this, a negative bias which has not been thoroughly investigated occurs.

5. Advantages and Disadvantages

5.1 The sampling device uses only filters and involves no liquids.

5.2 Oxidation of a significant fraction of the particulate sulfites and sulfur dioxide in the sample is unavoidable.

5.3 Because identification is based on retention time, interferences may not be easily identified (see Section 3.3).

SULFATES, SULFITES AND SULFUR DIOXIDE

Measurements Research Branch

Analytical Method

Analyte:	Sulfates, Sulfites and Sulfur Dioxide	Method No.:	P&CAM 268
Matrix:	Air	Range:	Sulfates: 0.1-10 mg/m^3 Sulfites: 0.1-10 mg/m^3 SO_2: 0.04-4 ppm (200-L air sample)
Procedure:	Particulate sulfates and sulfites collected on filter; SO_2 on treated filter; analysis by ion chromatography	Precision:	5% (Analytical)
Date Issued:	7/2/79		
Date Revised:		Classification:	E (Proposed)

1. Synopsis

A known volume of air is drawn through a filter train consisting of a cellulose ester membrane filter followed by an impregnated cellulose filter containing potassium hydroxide. Particulate matter, including sulfates and sulfites, is collected on the first filter, while sulfur dioxide passes through the first filter and is collected on the second filter.

The filters are extracted with deionized water and the extracts are analyzed by anion-exchange chromatography. The following quantities are obtained:

SO_2 concentration: calculated from the sulfite peak on the impregnated cellulose filter chromatogram.

Total sulfates concentration (sulfuric acid plus soluble metal sulfates): from the sulfate peak on the untreated cellulose ester membrane filter chromatogram.

Particulate sulfites concentration: from the sulfite peak on the untreated cellulose ester membrane filter chromatogram.

Shipping :

After sampling,the samples and the blank should be shipped in a suitable container designed to prevent damage in transit.

Reference:

"Sampling and Evaluating Respirable Coal Mine Dust", US Bureau of Mines, Pittsburgh, Pa. Information Circular 8503, February, 1971, p. 47.

Sampling Procedure:

1. Assemble the filter and three-piece filter cassette and close firmly to insure that the center ring seals the edge of the filter. Examine the holder for a good filter seal. If the cassette will not seal tightly, it should be discarded. If respirable dust is being measured, the center ring is not included in the filter holder. The filter cassette should be held together by a shrinking band or tape.

2. If total nuisance dust is being sampled, remove the filter holder plugs. Attach the filter holder to the sampling pump with a 1/4 inch diameter, 3-foot piece of tubing and an adaptor. The adaptor is used to provide a tight connection between the filter holder and tubing.

3. If the respirable dust is being sampled, assemble the two-piece filter holder, coupler, cyclone, and sampling head. The sampling head rigidly holds together the cyclone and filter holder. The outlet of the sampling head is connected to the pump by a 3-foot piece of 1/4 inch flexible tubing.

4. Clip the cassette or cyclone assembly to the worker's lapel.

5. Turn the pump on and begin sample collection. The pump flow rate should be checked periodically and readjusted if necessary.

6. Terminate sampling after the predetermined time and note sample flow rate, collection time, and ambient temperature and pressure. If a pressure reading is unavailable, record the elevation.

7. Collected sample cassette should be firmly sealed with the plugs in both the inlet and outlet.

8. With each batch of samples, submit one filter subjected to exactly the same handling as for the samples except that no air is drawn through it. Label these as blanks.

Special Considerations:

1. Filter holders molded from cellulose-acetate-butyrate, which is commonly known as Tenite plastic, have been shown to cause blank filter weight gains and must not be used.

2. The alignment of the filter holder and cyclone in the sampling head must be checked. If these parts are not aligned properly, leakage can result.

3. Before use, the cyclones grit cap or vortex finder should be removed and the interior of the cyclone should be inspected. If the inside of the cyclone is visibly scored, this cyclone should be discarded since the dust separation characteristics of the cyclone might be altered. If it is dirty, the interior of the cyclone should be cleaned before use. This will prevent the reentrainment of this dirt.

PARTICULATES

Substance:

Inert or Nuisance Dust

Standard:

8-hour time-weighted average for respirable dust: 5 mg/m^3

8-hour time-weighted average for total dust: 15 mg/m^3

Reference: 29 CFR 1910.93

Analytical Method:

The amount of material on a filter is determined by filter weight gain. Before sampling, the filter is pre-weighed to the nearest 0.01 mg. After sampling, the filter is reweighed. The difference in the filters weight is assumed to be the mass of material collected.

Sampling Equipment:

Pump: A calibrated personal sampling pump whose flow can be determined to an accuracy of $\pm$ 5%. The pump must have been calibrated with a representative filter and filter holder in line. If the respirable dust concentration is being measured, the pump must have a pulsation dampener and be certified under 30 CFR 74.

Filter Holder: 2 or 3-piece, 37-mm filter holder held together by tape or shrinking band.

Filter: 37-mm diameter, 5.0 micrometer pore size polyvinyl chloride filter or equivalent that has been pre-weighed to the nearest 0.01 mg. These filters must be hydrophobic. The filter should be supported with a back-up pad.

Cyclone: 10-mm nylon cyclone. When the respirable dust concentration is measured, it is used with a 2-piece filter holder.

Sampling Head Assembly: This assembly must hold the filter holder, cyclone, and coupler together rigidly so that air enters only at the cyclone inlet.

Sample Size:

A minimum sampling period of 60 minutes is recommended and longer periods up to eight hours are preferable. If the respirable dust concentration is being measured, a flow rate of 1.7 liters per minute must be used. To determine total dust concentration, use a flow rate of 1.5 liters per minute.

ODORANTS

To satisfy the need for an objective analytical technique for assessing diesel exhaust odorants as a group, the Diesel Odor Analysis System (DOAS) has been selected for use during this study.* The sampling portion of the DOAS method is based on the collection of filtered exhaust emissions over Chromosorb 102 adsorbent. The analytical portion of DOAS is performed by elution of the adsorbent with cyclohexane, separation with methanol, and analysis using silica gel liquid chromatography with ultraviolet absorption detection. The method separates the total organic extract into paraffinic and aromatic, and polar (oxygenated) fractions. Because previous sensory studies have shown that smoky-burnt odors are the prime contributors to the total diesel exhaust odor and that the smoky-burnt odor is associated with the polar (oxygenated) fraction, this fraction best assesses the total intensity of the odor or aroma.

The total intensity of the aroma (TIA) scale has been generally accepted as a useful means to subjectively quantify odors when the risks to human judges are low. During potentially high risk exposures, the DOAS produces results that can be compared with the TIA scale. A number of studies have shown that the DOAS method gives good correlation with diesel odor intensity as measured on the TIA scale. Equation 1 is used to estimate the TIA from DOAS polar fraction (methanol extract) data.

$$\mathrm{TIA} = 1.0 + 1.0 \log_{10} f \qquad \text{Eq. 1}$$

where: f = the polar fraction in mg/m^3

With $r^2 = 0.996$, and $26 = 0.32$, the ±0.32 TIA 95 percent confidence limits are better than normally observed (0.4) in odor observations.

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* Levins, P.L., et al. Chemical Analysis of Diesel Exhaust Odor Species. SAE Tech. Paper 740216, 1974.

5.6 A disadvantage is that a blank correction must be made for the fiber glass filter. Also, care must be taken to avoid evaporation of the extract to dryness.

5.7 A further disadvantage is that the ultrasonic extraction must be done in a sonabox to reduce the unacceptably high noise level.

6. Apparatus

6.1 Sonifier Cell Disruptor, 20 kHz power ultrasonic generator capable of dialing 70 watts accurately, with a 1.27-cm (½-inch) horn disruptor and Sonabox.

6.2 Liquid Chromatograph, with stainless steel column 2.6 × 300 mm, UV Detector with 254 nm filter and loop injector with a capacity ranging from 0.1 to 2 ml.

6.3 Strip Chart Recorder with Disc Integrator.

6.4 An approved and calibrated personal sampling pump for collection of particulate matter. Any vacuum pump whose flow can be determined accurately to within 1 lpm or less.

TABLE 4

Elution of Some Indoles, Carbazoles and Aromatic Aldehydes

Compound	t_R Min.	% Eluted Through Column	PA*/μg × 10⁻³
Indole	5.3	82	1.1
Carbazole	11.8	67	0.7
4-H-Benzo(def)carbazole	8.0	98	2.0
11-H-Benzo(a)carbazole	14.5	55	3.0
7-H-Dibenzo(c,g)carbazole	18.0	92	2.1
N-Phenylcarbazole	2.3	74	1.8
N-Ethylcarbazole	2.5	98	0.5
5-Methyl-5, 10-dihydroindeno(1,2-b) indole	2.8	103	1.9
2,3-Dimethylindole	5.3	90	5.5
2-Methylcarbazole	6.8	100	0.8
2-Hydroxycarbazole		Retained on column	
N-Ethyl-3-aminocarbazole		Retained on column	
Benzaldehyde	12.8	56	1.1
2-Naphthaldehyde	8.2	78	0.3

*Peak Area

TABLE 5

Comparison of Ultrasonic and Soxhlet Extractions

	Ultrasonic		Soxhlet	
Sample No.	PA/μg	% Eluted*	PA/μg	% Eluted*
1	0.575	51	0.449	28
2	0.562	53	0.509	—
3	0.567	50	0.500	—
4	0.579	48	0.545	31
5	0.560	44	—	—
6	0.573	44	—	—
Average	0.569	49	0.509	30
Rel. Std. Dev.	±1.33%		±26.1%	
Ultrasonic/Soxhlet Recovery = 1.14				

*Refers to % of TpAH in the extracted material.

TABLE 6

Recovery of Added PAH

Compound	Sample, μg	Peak Area: Sonified Filter + Std.	Peak Area: Standard Solution	% Recovery
Anthracene	0.035	1005	1055	95.0
Phenanthrene	0.147	1155	1185	97.5
Benzo(a)pyrene	0.355	1846	1880	98.2

6.5 Column Bypass.

6.6 Fisher Filtrator and medium sintered glass filter.

6.7 U.S. Standard Sieve Series No. 120, with 125-micron openings.

7. **Reagents**

7.1 Cyclohexane, ACS spectroanalyzed, distilled once from glass.

7.2 Polynuclear aromatic hydrocarbons.

7.3 Glass powder, spherical, non-wettable, 38-53 microns in diameter.

7.4 Corasil II.

8. **Procedure**

8.1 **Extraction**

8.1.1 The 1.27-cm horn of the sonifier cell disruptor is supported in a sonabox to reduce noise. The sonifying vessel is a beaker 3.8 cm I.D. × 10 cm tall. The end of the horn is set about 0.6 cm above the bottom of the beaker to insure adequate "stirring" of the mixture and equal exposure to areas of intense cavitation. Approximately 16 square cm of the exposed glass fiber filter and blank are cut into roughly 1.3-cm squares to facilitate shredding. The sonifying vessel is surrounded by an ice water bath up to the level of the solvent mixture.

8.1.2 Homogeneous replicate samples of approximately 16 square cm of exposed and blank glass fiber filters are prepared and adjusted to exactly 100 mg. This weight necessarily includes both the particulates and the glass fiber. These samples were used to maximize parameters and for comparison of ultrasonic and Soxhlet extractions, shown in Table 5.

8.1.3 Samples for routine analysis are not weighed. Only the areas of the sample (16 square cm) and the whole filter, the volume of air sampled and the volume of extract injected need to be determined. Sample at rate of at least 2 lpm for 1 hr or more.

8.1.4 Extraction Procedure. The sample, 60 ml cyclohexane, and 5 ml silica powder are placed in the sonifying vessel, and sonified for 8 min at 70 watts. The supernatant is decanted into the sintered glass filter supported on a Fisher Filtrator. Cyclohexane is added to the sonifying vessel to the level of the original mixture (usually about 50 ml). Sonification is carried on for an additional 4 minutes. The contents are filtered and combined with the first fraction, and rinsed with 50 ml cyclohexane. The filtrates and rinsings are collected in an Erlenmeyer flask and evaporated to about 5 ml, transferred quantitatively to a 10-ml volumetric flask and made to the mark.

8.1.5 Sample and blank filters (8.1.2) are extracted by Soxhlet with 80 ml cyclohexane for 6-8 hr, for comparison with the ultrasonic extraction. See Table 5. After filtering, the extracts are evaporated in the same manner as the ultrasonic extracts.

8.1.6 The glass fiber filters used for air sampling should be as free as possible of soluble compounds which absorb at 254 nm. It may be necessary to flash fire or extract them and care should be taken to avoid contaminating them.

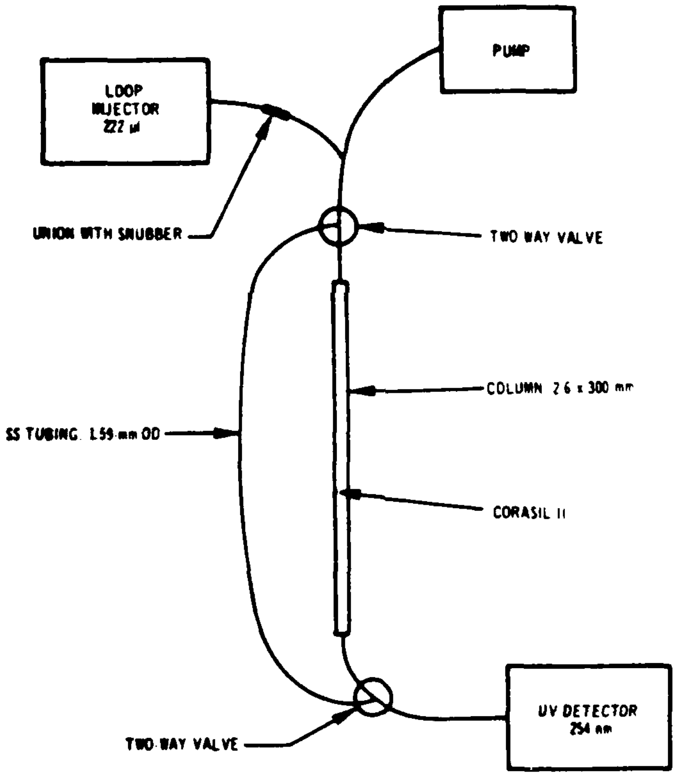

FIGURE 1. Schematic of Chromatographic System

8.2.2 To test the performance of the column, the percent of PAH which elutes is calculated from the peak areas through the column and the column bypass. Typical chromatograms from column and tubing are shown in Figure 2. Recovery of benzo(ghi)perylene was 99%. The percent of other hydrocarbons which eluted through the column ranged from 91 to 105, Table 1.

8.3 Analysis Procedure

8.3.1 An appropriate volume of extract is injected through the loop injector. A flow rate of 1.6 ml/min gives a pressure drop of less than 800 PSI. The peak area is measured with a disk integrator, driven by 0 to 10 servo strip chart recorder with a 0.5 in/min chart speed. The PAH elute in 3 to 5 min. Benzo(a)pyrene is used as the standard. Polar compounds are retained on the column. Samples can be chromatographed every 5 to 10 minutes.

8.3.2 The column bypass is also used to determine the percent of PAH in the organic material of the extract. Chromatograms of sample extracts made on the column and column bypass are shown in Figure 3. On the basis of absorbance measurements at 254 nm, approximately 50% of the organic material in the unchromatographed extract is PAH. This procedure is not necessary for routine analyses, but is helpful in elucidating the analytical situation in research samples.

8.4 Effects of Storage

8.4.1 Urban particulates on glass fiber filters stored in the dark in an envelope for one year lost 32% of their benzo(a)pyrene. Losses of some other PAH ranged from 1-88% (11.5).

8.4.2 Benzene-soluble extracts evaporated to dryness and stored in closed bottles in a refrigerator were stable (in terms of benzo(a)pyrene concentrations) for 4 years (11.6).

8.4.3 The ultrasonic extract is stable in the dark at room temperature for several days, longer in the refrigerator. However, losses usually occur after about two weeks.

9. Calibration and Standards

The benzo(a)pyrene (BaP) standard is made in cyclohexane and is chromatographed when the samples are run, and repeated whenever a parameter such as solvent lot is changed. Both standard and samples are run at concentrations which do not overload the detector and give reproducible results when diluted. For example, 0.4 μg BaP gave a peak area of about 2000 and fulfilled the above criteria.

The standard is expressed in terms of peak area per microgram (PA/μg). The unit of measurement for the samples is corrected peak area per cubic meter of air (PA/m^3). The BaP equivalent of the TpAH is calculated from these data (10.2). The standard is kept in the dark and is stable for more than 30 days when refrigerated nights and weekends.

10. Calculations

10.1 The peak area of the TpAH in a cubic meter of air is given by the equation

$$PA/m^3 = \frac{PA \times A \times B}{V \times a \times b}$$

where:

PA = Peak area, corrected for the blank
V = Volume of air sampled in m^3, corrected to 25°C and 760 Torr
A = Area of whole glass fiber filter in cm^2

B = Volume of extract in ml
a = Area of glass fiber filter sample in cm^2
b = Volume of extract injected in ml

10.2 The concentration of the TpAH may be expressed in terms of their equivalent in benzo(a)-pyrene.

$$\text{TpAH}(\mu g)/m^3 \text{ air} = \frac{\text{PA}/m^3 \text{ air (See Table 7)}}{\text{PA}/\mu g \text{ benzo(a)pyrene (See Table 1)}}$$

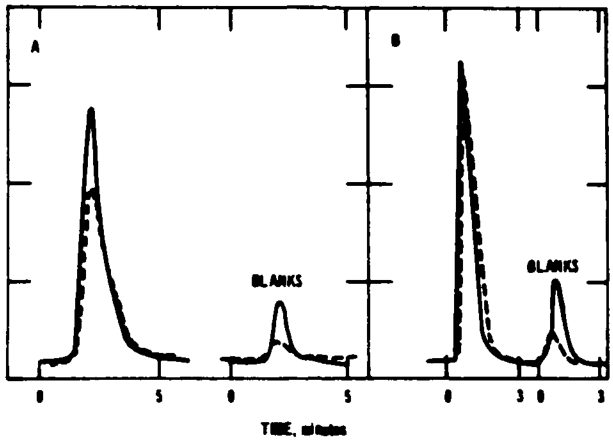

FIGURE 3. Chromatograms of ultrasonic and Soxhlet extracts of composited sample No. 1, Table 6 and blanks, through the column (A) and through the column bypass (B). Stationary phase, Corasil II; eluent, cyclohexane; flow rate, 1.6 ml/min. Solid lines are ultrasonic extracts; broken lines are Soxhlet extracts. Extracts were diluted x 3.3 for column bypass.

TABLE 7

Analysis of Particulate Samples

Description	Corrected Peak Area	m^3 Air Sampled	PA/m^3 Air[a]	TpAH[b] (μg)/m^3 Air
Urban I	1200	1500	1120	0.211
Urban II	620	1500	580	0.109
Urban III	545	1500	509	0.096
Mt. Storm	0	1673	0	0.000

[a]See Calculations—Section 10.1. [b]See Calculations—Section 10.2.

11. **References**

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APPENDIX B

CONTINUOUS AIR MONITORING DATA

NOTES ON CONTINUOUS AIR MONITORING DATA

FIELD DATA REDUCTION

During the magazine air monitoring, the Apple computer took approximately 45 readings per minute from each of the six instruments (SO_2, CO, NO, NO_x, and two air flow velometers). Approximately 3 million individual readings were taken during the period from July 23 through August 3, 1984. These readings were collected during: 6 unloading tests, 6 loading tests, and 28 warehousing tests. The sampling covered approximately 190 hours of air monitoring. At the end of each minute of sampling, an arithmetic average was calculated of the readings for each channel. At the end of each sampling period (5 or 15 minutes), these averages were written as a subfile onto the computers data disk.

A single sequential text file was created for each hour's data at each sampling location. Therefore, a single-hour file might contain as many as 12 individual sampling period subfiles (in the case of a 5-minute cycle at one location) or as few as 1 sampling period subfile (in the case of a 15-minute cycle with four locations). Each subfile begins with the first minute of the sampling period (e.g., 5, 10, 15, etc.). This is followed by an 8 x SP matrix containing the 1-minute averages (where SP is the length of the sampling period). A 15-minute sampling period therefore contains 120 entries after the starting minute figure. An entry of "****" was used whenever an instrument was off line.

CALCULATION OF AVERAGE READINGS

The field sampling sequence operated on either a 5-minute cycle or a 15-minute cycle. At the end of each cycle, the sampling location was switched to the next location in the sequence. Although individual 1-minute readings were stored on the computer's data disks to simplify the data analysis, it was desirable to calculate averages for the entire sampling period of each instrument. Because of the slow response time of some instruments, the first few minutes of data recorded after a switch in location could not always be considered valid. The following 1-minute readings were therefore averaged to come up with the overall average for the two types of sampling periods:

	Minutes averaged	
Channel	5-minute cycle	15-minute cycle
SO_2	4-5	4-15
CO	2-5	2-15
NO	3-5	3-15
NO_x	3-5	3-15
Air 1	1-5	1-15
Air 2	1-5	1-15

ZERO-DRIFT CORRECTIONS

During air monitoring of the forklift operations, continuous monitors may experience slight drifts in their zero response. This drift is detected from the output of each instrument's "backup" strip-chart recorder. The zero drift experienced during the tests was negligable (less than 5 percent of the average reading) for all instruments, therefore no zero-drift corrections were needed.

DATA TABLE DESCRIPTION

The continuous monitoring data are presented for each vehicle test (by sampling location) for sulfur dioxide, carbon monoxide, nitric oxide, and oxides of nitrogen. The recorded air velocities detected at each ventilation duct are also presented.

The schedule of the test operations is presented in Table B-1. The actual test data are presented on Tables B-2 through B-49. Data is identified by each test (1-29) operation (loading, unloading or warehousing), vehicle type, magazine type and sampling location.

TABLE 3. SCHEDULE OF TEST OPERATIONS

Test number	Date	Operation/vehicle	Magazine/ sampling location
1	7/23/84	Unloading - Still/Deutz (No. 1)	Stradley (B) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (B) - Rear
		Loading - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Loading - Hyster/Isuzu (No. 2)	Stradley (A) - Rear
2	7/24/84	Unloading - Still/Deutz (No. 1)	Stradley (A) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (A) - Rear
		Loading - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Loading - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
3	7/24/84	Warehousing - Hyster/Perkins (No. 3)	Igloo (C) - Center
4	7/25/84	Unloading - Still/Deutz (No. 1)	Stradley (B) - Forward
		Unloading - Still Deutz (No. 1)	Stradley (B) - Rear
		Loading - Hyster/Perkins (No. 3)	Stradley (A) - Forward
		Loading - Hyster/Perkins (No. 3)	Stradley (A) - Rear
5	7/25/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
6	7/26/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
7	7/26/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
8	7/27/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Rear
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Rear
9	7/27/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Rear
		Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Rear

TABLE 3 (continued)

Test number	Date	Operation/vehicle	Magazine/ sampling location
10	7/30/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Forward
11	7/30/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Forward
12	7/30/84	Warehousing - Baker/Deutz (No. 4)	Igloo (C) - Center
13	7/31/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (B) - Forward
14	7/31/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
15	7/31/84	Warehousing - Hyster/Perkins (No. 3)	Igloo (C) - Center
16	7/31/84	Unloading - Hyster/Perkins (No. 3)	Igloo (C) - Center
17	7/31/84	Loading - Hyster/Perkins (No. 3)	Igloo (C) - Center
18	8/1/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (B) - Rear
19	8/1/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Rear
20	8/1/84	Unloading - Hyster/Isuzu (No. 2)	Igloo (C) - Center
21	8/1/84	Loading - Hyster/Isuzu (No. 2)	Igloo (C) - Center
22	8/1/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
23	8/2/84	Unloading - Baker/Deutz (No. 4)	Igloo (C) - Center

TABLE 3 (continued)

Test number	Date	Operation/vehicle	Magazine/ sampling location
24	8/2/84	Loading - Baker/Deutz (No. 4)	Igloo (C) - Center
25	8/3/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
		Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward
26	8/3/84	Warehousing - Hyster/Perkins (No. 3)	Stradley (B) - Forward
27	8/3/84	Warehousing - Hyster/Isuzu (No. 2)	Igloo (C) - Center
28	8/3/84	Warehousing - Baker/Deutz (No. 4)	Igloo (C) - Center
29	8/3/84	Warehousing - Hyster/Isuzu (No. 2)	Stradley (B) - Forward
30	8/3/84	Warehousing - Baker/Deutz (No. 4)	Stradley (A) - Forward

TABLE B-2. TEST NUMBER 1: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still/Deutz (No. 1)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:20	10	76	0.4	****	****	882	610
10:40	30	97	0.6	49	83	1149	818
11:00	50	160	0.9	414	467	1220	676
11:20	70	633	1.0	1431	1640	840	527
11:40	90	197	1.4	695	748	1165	1069
12:00	110	337	****	1038	1143	1184	666
12:20	130	591	1.3	1845	2033	1049	863
12:40	150	176	0.8	491	563	916	898
13:05	175	340	3.0	921	1025	982	1051
13:25	195	344	2.8	771	899	1473	1344
13:45	215	447	3.5	1184	1207	1481	1175
14:05	235	506	3.5	****	****	1361	1470
14:25	255	573	4.1	2028	1962	1145	1063
14:45	275	327	3.4	1001	1047	1078	1259
15:05	295	412	4.5	1186	1420	1230	918
15:25	315	240	3.0	707	794	1310	1131
15:45	335	426	3.4	1042	1152	1541	1576
16:00	350	****	****	852	949	1283	1185
16:10	360	306	3.2	780	827	1219	852
16:30	380	326	2.9	710	789	1320	1364
16:50	400	288	3.1	699	803	1606	1632
17:10	420	298	3.3	739	822	1165	923
17:30	440	652	3.7	1189	1285	601	609
17:50	460	****	****	****	****	****	****
Mean		352	2.6	941	1031	1183	1028
Maximum		652	4.5	2028	2033	1606	1632
Time at maximum		17:30	15:05	14:25	12:20	16:50	16:50

TABLE B-3. TEST NUMBER 1: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still/Deutz (No. 1)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:25	15	****	0.9	35	46	991	812
10:45	35	****	0.3	122	158	1194	614
11:05	55	194	0.9	549	607	1082	665
11:25	75	[illegible]	1.2	1064	1127	1011	972
11:45	95	249	1.4	964	1054	839	765
12:05	115	285	****	939	1037	934	877
12:25	135	410	1.1	1290	1367	1095	885
12:45	155	271	0.9	769	884	1170	509
13:10	190	337	3.0	599	674	1406	1176
13:30	200	382	3.1	959	1119	1396	1290
13:50	220	692	3.9	1390	1431	1398	1277
14:10	240	588	3.5	****	****	1275	1583
14:30	260	676	3.4	1900	2050	1114	1073
14:50	280	48	3.6	1498	1691	1143	1160
15:10	300	624	3.7	1713	1857	1247	868
15:30	320	651	3.4	1331	1451	1374	1255
15:50	340	****	****	1978	2112	1334	1322
16:15	365	411	3.4	1582	1805	931	826
16:35	385	635	3.3	1221	1378	1467	1282
16:55	405	729	3.1	1735	1919	1538	1586
17:15	425	481	3.7	1249	1377	1045	838
17:35	445	1018	3.3	3310	3393	684	721
17:55	465	****	****	****	****	****	****
Mean		469	2.6	1243	1359	1164	1024
Maximum		1018	3.9	3310	3393	1538	1586
Time at maximum		17:35	13:50	17:35	17:35	16:55	16:55

TABLE B-4. TEST NUMBER 1: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:10	0	0	0.0	0	0	0	0
10:30	20	204	0.9	266	324	923	661
10:50	40	****	1.5	717	915	1236	923
11:10	60	151	1.5	646	777	993	541
11:30	80	170	1.6	578	654	1189	844
11:50	100	335	2.3	1063	1258	900	567
12:10	120	417	****	993	1132	1185	683
12:30	140	367	1.2	1035	1277	1223	1026
13:10	180	44	3.8	1050	1333	1406	1343
13:35	205	853	4.7	1689	2045	1399	1367
13:55	225	67	5.6	2789	3028	1329	1366
14:15	245	91	4.3	2111	2251	1345	1451
14:35	265	41	4.0	1507	1674	1079	1088
14:55	285	335	3.7	1053	1311	1155	1169
15:15	305	341	3.8	974	1292	1233	1215
15:35	325	357	3.6	834	949	1149	1014
15:50	340	373	3.4	945	1173	1679	1482
16:00	350	196	3.4	474	601	1482	1314
16:20	370	443	4.0	1394	1643	1069	993
16:40	390	158	3.1	503	608	1466	1477
17:00	410	331	3.6	936	1149	1161	1174
17:20	430	308	3.8	1331	1625	849	855
17:40	450	****	****	****	****	****	****
Mean		368	3.0	1042	1224	1157	1024
Maximum		853	5.6	2789	3028	1679	1482
Time at maximum		13:35	13:55	13:55	13:55	15:50	15:50

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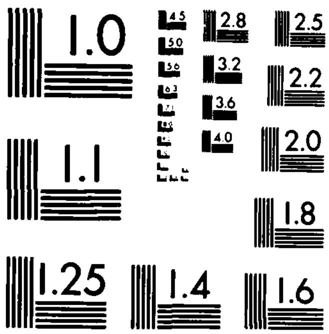

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TABLE B-5. TEST NUMBER 1: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:15	5	64	0.5	28	2	1120	708
11:15	65	488	2.0	1557	1947	1072	773
11:35	85	583	2.3	1547	1796	1202	809
11:55	105	585	2.7	1488	1760	1300	701
12:15	125	527	1.4	1410	1737	1004	686
12:35	145	371	1.6	1077	1339	962	1013
12:55	165	****	****	****	****	1229	1123
13:00	170	419	3.8	1009	1159	1149	1228
13:20	190	309	3.6	967	1188	1394	1244
13:40	210	486	4.3	1361	1503	1339	1263
14:00	230	200	3.6	933	1060	1360	1418
14:20	250	498	3.8	1472	1709	1317	1399
14:40	270	292	3.8	****	****	1106	1387
15:00	290	303	3.6	820	1021	1156	1121
15:20	310	340	3.9	739	910	1189	1117
15:40	330	239	3.5	747	863	1412	1109
15:55	345	262	3.6	916	1138	1248	1067
16:05	355	364	3.8	974	1147	1118	901
16:25	375	152	3.5	723	901	1268	1224
16:45	395	229	3.3	608	756	1388	1435
17:05	415	472	3.8	1199	1472	1251	1218
17:25	435	144	3.2	475	592	767	839
17:45	455	****	****	****	****	****	****
Mean		349	3.1	1003	1200	1198	1081
Maximum		585	4.3	1557	1947	1412	1435
Time at maximum		11:55	13:40	11:15	11:15	15:40	16:45

TABLE B-6. TEST NUMBER 2: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still-Deutz (No. 1)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:10	0	42	1.5	35	10	1795	1696
8:30	20	93	1.9	431	506	1578	1732
8:50	40	421	2.4	1703	1844	1778	1605
9:10	60	875	2.9	2518	2675	1751	1725
9:30	80	728	2.9	2197	2493	1413	1326
9:50	100	385	2.9	1278	1360	1425	1556
10:10	120	359	2.8	1107	1167	1272	1609
10:30	140	602	3.1	1443	1626	1370	1588
10:50	160	892	3.5	1959	2167	1622	1721
11:10	180	956	3.5	2519	2541	1772	1764
11:30	200	538	3.2	1621	1897	1963	1782
11:50	220	568	3.4	1638	1821	2039	2122
12:10	240	615	3.0	1737	2018	1640	1574
12:30	260	355	2.9	795	915	1284	1378
12:50	280	847	3.5	1413	1639	1688	1730
13:10	300	497	3.3	1188	1249	1270	1618
13:30	320	290	2.8	777	812	1542	1517
13:50	340	341	2.6	812	932	1601	1630
14:10	360	354	3.0	919	1037	1306	1408
14:30	380	256	2.6	669	729	2181	2164
14:50	400	232	2.6	699	748	2275	2227
15:10	420	193	2.6	564	659	2169	2106
15:30	440	406	2.6	1156	1278	1703	1801
15:50	460	205	2.5	566	622	2228	2038
16:10	480	302	2.6	718	816	2049	2058
16:30	500	111	2.4	300	338	1988	2020
16:50	520	****	****	****	****	2010	1967
Mean		441	2.8	1183	1304	1730	1758
Maximum		956	3.5	2519	2675	2275	2227
Time at maximum		11:10	11:10	11:10	9:10	14:50	14:50

TABLE B-7. TEST NUMBER 2: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still-Deutz (No. 1)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:15	5	41	1.5	35	10	1797	1676
8:35	25	224	2.2	752	776	1749	1717
8:55	45	607	2.7	2269	2525	1790	1747
9:15	65	866	3.0	2501	2679	1191	1287
9:35	85	351	2.8	1690	1818	1647	1667
9:55	105	246	2.6	1120	1197	1677	1655
10:15	125	394	3.0	1425	1538	1092	1006
10:35	145	704	3.3	1849	2022	1176	1357
10:55	165	438	3.2	1367	1481	1885	1868
11:15	185	655	3.5	1943	1968	1478	1500
11:35	205	572	3.1	1423	1575	1556	1551
11:55	225	353	3.0	1151	1221	2076	2000
12:15	245	419	3.0	1361	1470	1869	1768
12:35	265	535	3.2	1673	1760	1849	1774
12:55	285	699	3.3	1745	1846	1656	1610
13:15	305	249	2.8	1141	1180	1816	1645
13:35	325	328	2.7	1031	1140	1282	1297
13:55	345	624	2.9	1599	1809	2029	2102
14:15	365	550	3.0	1665	1775	1767	1800
14:35	365	528	2.6	1448	1563	1770	1688
14:55	405	577	2.6	1363	1859	2063	1932
15:15	425	540	2.7	1487	1643	1581	1689
15:35	445	782	2.8	2250	2731	1559	1549
15:55	465	555	2.9	1388	1272	2139	2094
16:15	485	910	2.9	2092	2312	1943	1862
16:35	505	****	****	****	****	****	****
Mean		508	2.8	1511	1647	1697	1674
Maximum		910	3.5	2501	2731	2139	2102
Time at maximum		16:15	11:15	9:15	15:35	15:55	13:55

TABLE B-8. TEST NUMBER 2: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:20	10	456	4.0	760	753	2000	1752
8:40	30	806	4.3	2353	2604	1456	1499
9:00	50	643	4.3	1654	1847	1768	1640
9:20	70	786	4.7	2166	2588	1318	1395
9:40	90	487	3.8	1586	1785	1679	1614
10:00	110	600	3.7	1553	1732	1241	1327
10:20	130	730	4.1	1805	2092	1588	1491
10:40	150	871	5.2	2365	2743	1737	1636
11:00	170	1112	5.2	2606	3122	1298	1355
11:20	190	985	5.0	2197	2563	1756	1593
11:40	210	728	4.2	1600	1945	1223	1207
12:00	230	795	4.3	1893	2271	1747	1625
12:20	250	900	4.2	2154	2520	1590	1798
12:40	270	756	4.1	1862	2230	1448	1419
13:00	290	1014	4.4	2190	2475	1492	1535
13:20	310	226	3.0	593	667	1683	1719
13:40	330	237	2.9	420	504	1435	1449
14:00	350	449	3.2	901	1033	1897	1926
14:20	370	469	3.0	1192	1417	1758	2010
14:40	390	424	3.1	893	1083	2082	1988
15:00	410	345	2.9	711	809	2063	2048
15:20	430	529	3.2	1676	1965	1587	1641
15:40	450	273	2.7	658	791	1960	1941
16:00	470	170	2.5	327	416	1960	1985
16:20	490	68	2.4	62	95	2042	2029
16:40	510	****	****	****	****	****	****
Mean		594	3.8	1447	1682	1672	1665
Maximum		1112	5.2	2606	3122	2082	2048
Time at maximum		11:00	11:00	11:00	11:00	14:40	15:00

TABLE B-9. TEST NUMBER 2: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:25	15	806	3.5	2369	2638	1847	1716
8:45	35	1314	5.6	3191	3562	1616	1652
9:05	55	1185	5.0	2674	2826	1858	1757
9:25	75	1421	5.9	3231	3878	1005	1168
9:45	95	727	4.2	2017	2231	1608	1575
10:05	115	1041	4.8	2244	2675	1044	1212
10:25	135	1078	4.8	2039	2383	1497	1626
10:45	155	1176	5.8	2744	3248	1770	1815
11:05	175	1372	5.9	3331	3792	1325	1375
11:25	195	723	4.5	1689	1990	1840	1614
11:45	215	389	3.7	1145	1344	1774	1966
12:05	235	569	3.9	1371	1601	1798	1776
12:25	255	310	3.4	1196	1518	1226	1154
12:45	275	1044	4.7	1920	2154	1873	1893
13:05	295	930	4.6	2278	2543	1340	1341
13:25	315	592	3.7	1223	1424	1913	1781
13:45	335	483	3.3	1088	1413	1302	1221
14:05	355	460	3.2	978	1146	1756	1762
14:25	375	380	3.1	904	1075	1920	1903
14:45	395	495	3.2	1026	1214	2015	1972
15:05	415	241	2.8	640	778	2263	2282
15:25	435	312	3.0	1043	1206	1679	1710
15:45	455	481	3.3	1026	1193	1714	1571
16:05	475	129	2.7	351	435	2171	2124
16:25	495	69	2.2	61	67	1989	1940
16:45	515	****	****	****	****	****	****
Mean		709	4.0	1671	1933	1686	1676
Maximum		1421	5.9	3331	3878	2263	2282
Time at maximum		9:25	9:25	11:05	9:25	15:05	15:05

TABLE B-10. TEST NUMBER 3: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
12:30	0	0.00	0.00
12:40	10	9.44	9.01
12:50	20	15.25	14.21
13:00	30	17.36	20.19
13:10	40	20.52	22.53
13:20	50	18.15	22.53
Mean		13.45	14.75
Maximum		20.52	22.53
Time at Maximum		13:10	13:20

TABLE B-11. TEST NUMBER 4: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still/Deutz (No. 1)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
7:55	10	****	****	****	****	****	****
8:10	25	1	0.1	39	31	418	426
8:55	70	533	1.1	3380	3792	522	490
9:15	90	394	1.1	2235	2463	498	486
9:35	110	395	0.9	2669	2876	498	473
9:55	130	217	0.7	1531	1781	457	433
10:15	150	269	0.6	1808	1992	472	431
10:35	170	168	0.6	1311	1493	452	426
10:55	190	309	0.8	1913	2160	441	426
11:15	210	446	0.9	2250	2557	493	459
11:35	230	276	0.8	1761	1980	436	431
11:55	250	649	1.3	2684	3012	436	410
12:15	270	220	0.7	1426	1631	450	417
12:35	290	430	0.8	2207	2523	431	374
12:55	310	403	1.0	2517	2781	433	429
13:15	330	416	0.9	2433	2793	444	442
13:35	350	378	0.9	2451	2794	549	551
13:55	370	292	0.8	2029	2246	541	494
14:15	390	318	0.8	2085	2359	560	582
14:35	410	356	1.1	2144	2445	507	478
14:55	430	423	1.1	2550	2865	470	427
15:15	450	567	1.3	2411	2472	502	409
15:35	470	551	1.5	2582	2707	459	434
15:55	490	231	1.5	1981	2067	465	412
16:15	510	****	****	****	****	****	****
Mean		358	0.9	2104	2340	475	450
Maximum		649	1.5	3380	3792	560	582
Time at maximum		11:55	15:35	8:55	8:55	14:15	14:15

TABLE B-12. TEST NUMBER 4: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Still/Deutz (No. 1)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:15	30	8	0.1	29	8	493	460
9:00	75	230	1.3	3392	3698	552	537
9:20	95	249	1.0	2829	3048	528	509
9:40	115	204	0.8	2870	3044	491	448
10:00	135	78	0.7	1506	1595	435	420
10:20	155	89	0.6	1349	1441	471	455
10:40	175	105	0.6	1379	1499	440	417
11:00	195	96	0.7	1685	1843	479	458
11:20	215	151	0.8	1514	1646	494	448
11:40	235	127	0.7	1250	1372	476	415
12:00	255	255	0.9	1858	2061	445	417
12:20	275	207	0.7	1678	1875	449	426
12:40	295	167	0.8	1694	1928	430	405
13:00	315	194	0.7	1781	2032	346	395
13:20	335	243	0.8	2089	2322	444	431
13:40	355	249	0.9	2049	2337	571	529
14:00	375	133	0.5	1415	1610	620	573
14:20	395	231	0.6	1798	1981	572	578
14:40	415	375	1.0	1948	2006	474	478
15:00	435	248	1.0	2015	2303	515	458
15:20	455	440	1.1	2118	2124	527	494
15:40	475	492	1.6	2398	2387	448	471
16:00	495	133	1.1	1399	1460	253	302
16:20	515	****	****	****	****	****	****
Mean		205	0.8	1828	1984	476	458
Maximum		492	1.6	3392	3698	620	578
Time at maximum		15:40	15:40	9:00	9:00	14:00	14:20

TABLE B-13. TEST NUMBER 4: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
7:45	0	4	0.3	455	473	450	430
7:55	10	182	0.6	1036	997	419	414
8:00	15	126	1.1	1731	1838	429	417
8:20	35	318	1.5	2039	2314	441	419
8:45	60	****	****	2233	2638	427	424
9:05	80	413	3.0	2653	3013	531	507
9:25	100	345	3.0	2530	2842	540	509
9:45	120	267	2.0	1969	2188	494	450
10:05	140	277	2.1	1929	2212	439	423
10:25	160	296	1.9	1760	2180	472	437
10:45	180	266	2.1	1917	2337	425	415
11:05	200	461	3.1	3033	3462	474	452
11:25	220	864	4.9	5585	6736	464	416
11:45	240	723	4.1	3213	3666	445	395
12:05	260	916	5.5	4198	4999	417	396
12:25	280	581	4.1	3255	4073	432	386
12:45	300	851	5.1	4795	5094	406	416
13:05	320	920	5.7	4778	5376	440	422
13:25	340	773	4.4	3652	4753	426	410
13:45	360	505	3.1	2942	3477	563	541
14:05	380	590	4.1	2613	3417	638	592
14:25	400	475	3.5	1953	2685	626	614
14:45	420	493	3.1	2935	3489	493	454
15:05	440	446	3.4	2612	3345	412	453
15:25	460	372	3.3	2321	2774	489	438
15:45	480	167	2.1	1730	2142	553	507
16:05	500	****	****	****	****	****	****
16:25	520	****	****	****	****	****	****
Mean		465	3.1	2687	3174	475	451
Maximum		920	5.7	5585	6736	638	614
Time at maximum		13:05	13:05	11:25	11:25	14:05	14:25

TABLE B-14. TEST NUMBER 4: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
7:50	5	344	2.5	1664	1976	420	410
8:05	20	472	2.8	2438	2821	404	411
8:25	40	****	****	****	****	445	419
8:50	65	475	2.8	2720	3291	444	431
9:10	85	896	6.1	5983	6984	500	454
9:30	105	1023	6.2	6201	7118	553	502
9:50	125	527	3.9	3825	4359	492	449
10:10	145	791	5.2	4003	4664	474	448
10:30	165	449	3.6	2892	3537	452	427
10:50	185	432	3.9	2876	3571	426	416
11:10	205	874	6.5	5045	5985	461	437
11:30	225	876	6.4	5675	6682	464	425
11:50	245	543	4.0	4189	5161	410	424
12:10	265	661	5.0	4046	4881	459	441
12:30	285	640	5.8	3593	4524	427	395
12:50	305	555	4.8	3944	4638	438	409
13:10	325	536	4.4	4361	5296	460	424
13:30	345	587	4.3	3877	4789	526	526
13:50	365	373	3.1	2694	3122	499	460
14:10	385	341	3.6	2073	2587	516	546
14:30	405	386	3.9	2012	2447	569	554
14:50	425	497	4.4	3100	3647	468	397
15:10	445	492	3.9	3229	3882	437	412
15:30	465	235	3.1	2876	3254	455	471
15:50	485	143	2.5	2178	2544	443	422
16:10	505	****	****	****	****	****	****
Mean		546	4.3	3562	4240	466	444
Maximum		1023	6.5	6201	7118	569	554
Time at maximum		9:30	11:10	9:30	9:30	14:30	14:30

TABLE B-15. TEST NUMBER 5: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
14:00	0	0.00	0.00
14:10	10	.46	1.47
14:20	20	5.21	6.41
14:30	30	7.85	9.53
14:40	40	10.49	12.65
14:50	50	10.76	12.65
15:00	60	10.49	12.39
15:10	70	10.76	12.65
15:20	80	10.49	12.13
15:30	90	9.97	12.65
15:40	100	9.17	10.83
15:50	110	8.65	10.57
Mean		7.94	9.49
Maximum		10.76	12.65
Time at Maximum		14:50	14:40

TABLE B-16. TEST NUMBER 6: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:25	0	330	1.7	537	682	577	557
10:35	10	1009	3.3	2360	2848	521	527
10:45	20	1283	3.2	3084	3680	565	559
10:55	30	1030	3.2	2432	3129	513	523
11:05	40	767	2.6	1933	2228	584	571
11:15	50	811	3.0	2123	2686	602	610
11:25	60	950	2.7	2582	3115	593	579
11:35	70	793	2.4	2544	2990	610	601
11:45	80	1093	3.1	2941	3576	595	609
11:55	90	947	2.7	2734	3146	570	585
12:05	100	917	2.9	2634	3211	537	552
12:15	110	777	2.7	2417	2890	553	530
12:25	120	691	3.1	2180	2677	533	517
12:35	130	745	2.8	1900	2358	573	598
12:45	140	761	2.7	1790	2199	556	536
12:55	150	861	2.6	1994	2459	597	589
13:05	160	652	2.8	2099	2530	554	595
13:15	170	707	2.5	2276	3116	523	574
[illegible]	180	789	2.4	2389	2965	428	496
[illegible]	190	1004	3.3	2882	3267	571	596
Mean		846	2.8	2292	2788	558	565
Maximum		1283	3.3	3084	3680	610	610
Time at maximum		10:45	10:35	10:45	10:45	11:35	11:15

TABLE B-30. TEST NUMBER 14: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
12:55	5	41	0.5	62	13	404	451
13:05	15	416	1.4	2268	2721	536	433
13:15	25	702	1.9	2671	3193	577	560
13:25	35	595	2.0	2540	3146	492	489
13:35	45	687	2.5	2830	3255	523	491
13:45	55	730	2.6	2627	3287	421	414
13:55	65	700	2.5	2581	3100	469	440
14:05	75	864	2.8	3491	4168	531	397
14:15	85	740	2.4	3101	3538	512	506
14:25	95	795	2.4	2897	3638	589	505
14:35	105	745	2.2	3005	3540	618	490
14:45	115	870	2.8	3170	3880	483	460
14:55	125	906	2.7	3212	3712	529	471
15:05	135	638	2.2	2462	3125	494	446
15:15	145	633	2.0	2889	3437	537	417
15:25	155	622	2.2	2365	2730	558	486
15:35	165	1078	2.9	3430	4038	459	412
15:45	175	893	2.9	3494	3940	585	506
15:55	185	914	2.9	3425	4007	527	447
Mean		714	2.3	2764	3288	518	464
Maximum		1078	2.9	3494	4168	618	560
Time at maximum		15:35	15:35	15:45	14:05	14:35	13:15

TABLE B-29. TEST NUMBER 13: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:25	5	809	3.1	6662	7758	428	403
8:35	15	952	3.2	7330	8067	429	426
8:45	25	1231	4.4	9724	10101	380	390
8:55	35	1001	4.0	8833	9638	440	417
9:05	45	1191	4.4	9711	9997	421	397
9:15	55	1041	4.6	9694	10034	424	425
9:25	65	1262	4.8	9835	10104	384	423
9:35	75	1094	5.1	9863	10104	363	408
9:45	85	1409	5.3	10075	10104	437	439
9:55	95	1095	4.6	9796	10104	493	461
10:05	105	1443	5.7	10075	10080	466	469
10:15	115	1641	6.4	10075	10104	446	448
10:25	125	1081	5.0	9611	9957	381	377
10:35	135	1113	4.9	9871	10104	339	387
10:45	145	860	3.8	9252	9921	479	472
10:55	155	1115	4.6	9954	10104	439	441
11:05	165	1363	5.3	10054	10043	474	452
11:15	175	1106	4.9	9646	9941	470	462
11:25	185	****	****	****	****	416	333
11:35	195	****	****	****	****	381	360
11:45	205	****	****	****	****	450	378
11:55	215	****	****	****	****	524	431
Mean		1156	4.7	9448	9793	430	419
Maximum		1641	6.4	10075	10104	524	472
Time at maximum		10:15	10:15	9:45	9:25	11:55	10:45

TABLE B-28. TEST NUMBER 13: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:20	0	46	3.3	2752	3056	386	394
8:30	10	450	1.9	2554	3124	409	418
8:40	20	609	2.5	3043	3410	454	402
8:50	30	898	2.9	3955	4674	425	417
9:00	40	655	2.9	3352	3943	398	412
9:10	50	720	3.3	3565	4324	418	424
9:20	60	720	3.4	3549	4180	421	409
9:30	70	754	3.5	3950	4946	407	390
9:40	80	757	3.6	4019	4789	407	421
9:50	90	669	3.8	3933	4758	465	462
10:00	100	719	3.4	3664	4516	503	491
10:10	110	821	3.2	3582	4451	342	386
10:20	120	713	3.1	3682	4605	408	406
10:30	130	812	3.5	3926	5043	360	379
10:40	140	759	3.0	3527	4182	484	510
10:50	150	850	3.3	3508	4337	462	440
11:00	160	819	3.1	3828	4809	427	446
11:10	170	770	3.3	3692	4458	478	465
11:20	180	****	****	****	****	477	477
11:30	190	****	****	****	****	384	351
11:40	200	****	****	****	****	389	359
11:50	210	****	****	****	****	477	520
12:00	220	****	****	****	****	****	****
Mean		708	3.2	3560	4311	426	426
Maximum		898	3.8	4019	5043	503	520
Time at maximum		8:50	9:50	9:40	10:30	10:00	11:50

TABLE B-27. TEST NUMBER 12: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
13:08	0	0.00	0.00
13:18	10	7.59	10.83
13:28	20	14.19	15.77
13:38	30	13.93	15.51
13:48	40	14.72	17.07
13:58	50	15.51	16.55
14:08	60	14.98	14.99
14:18	70	13.93	14.21
14:28	80	13.13	13.43
14:38	90	12.61	14.21
14:48	100	12.34	15.51
14:58	110	13.93	14.99
15:08	120	13.66	14.99
15:18	130	13.13	14.73
15:28	140	12.61	16.03
15:38	150	13.93	15.25
15:48	160	13.4	15.25
15:58	170	13.66	14.73
Mean		12.63	14.11
Maximum		15.51	17.07
Time at Maximum		13:58	13:48

TABLE B-26. TEST NUMBER 11: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
12:55	0	439	1.8	937	986	414	367
13:05	10	574	3.9	4395	4942	396	350
13:15	20	826	5.8	5060	6783	401	371
13:25	30	1214	7.9	7350	8414	456	404
13:35	40	806	6.2	6418	6948	530	447
13:45	50	811	5.6	5858	6588	483	491
13:55	60	1118	6.7	5592	6262	428	378
14:05	70	866	6.5	5364	6375	350	360
14:15	80	930	7.1	5893	6657	488	465
14:25	90	1511	9.5	7697	9024	470	461
14:35	100	949	8.3	6474	8005	493	508
14:45	110	1527	9.9	8342	9469	536	460
14:55	120	902	8.4	7019	8115	475	436
15:05	130	1054	8.1	6942	8104	492	443
15:15	140	845	7.6	6304	6664	531	477
15:25	150	833	6.6	6283	7378	463	389
15:35	160	873	6.7	6225	7713	402	397
15:45	170	816	6.3	4734	5710	526	504
15:55	180	636	5.3	3755	4684	497	429
Mean		922	6.7	5823	6780	465	428
Maximum		1527	9.9	8342	9469	536	508
Time at maximum		14:45	14:45	14:45	14:45	14:45	14:35

TABLE B-25. TEST NUMBER 11: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:00	5	994	1.7	2037	2430	369	397
13:10	15	833	2.7	3289	3827	489	415
13:20	25	1092	3.2	4031	4739	413	372
13:30	35	1053	3.3	4692	5340	368	387
13:40	45	997	2.9	3840	4583	423	366
13:50	55	865	2.9	3775	4310	435	415
14:00	65	621	2.1	2853	3463	402	378
14:10	75	788	2.5	2890	3761	432	440
14:20	85	693	2.2	2806	3479	429	377
14:30	95	720	2.5	3007	3606	407	407
14:40	105	843	2.9	2944	3905	472	437
14:50	115	919	3.3	3432	4213	426	421
15:00	125	1104	3.5	3705	4740	470	471
15:10	135	910	3.3	4153	4750	491	437
15:20	145	1017	2.7	4246	4861	503	422
15:30	155	966	2.9	3976	4654	454	350
15:40	165	908	2.9	3597	4261	445	418
15:50	175	1295	3.6	4136	4933	479	458
Mean		923	2.8	3523	4214	439	409
Maximum		1295	3.6	4692	5340	503	471
Time at maximum		15:50	15:50	13:30	13:30	15:20	15:00

TABLE B-24. TEST NUMBER 10: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
9:05	5	1811	9.5	7767	7905	473	439
9:15	15	1518	8.1	8802	9140	433	443
9:25	25	1072	6.6	7553	8379	384	362
9:35	35	1484	9.3	9323	9723	422	420
9:45	45	707	5.1	6328	7118	377	351
9:55	55	922	6.9	5904	6579	406	381
10:05	65	1044	6.6	6961	7997	349	371
10:15	75	1109	7.4	6349	7514	336	334
10:25	85	1345	9.4	7174	8074	360	366
10:35	95	1032	8.5	7436	8557	403	391
10:45	105	883	8.1	6817	7734	377	366
10:55	115	1073	9.2	7250	8334	404	336
11:05	125	1222	9.4	8223	9439	419	404
11:15	135	910	7.8	6492	7765	351	349
11:25	145	753	6.6	6245	7066	392	340
11:35	155	1017	8.5	6841	8151	353	402
11:45	165	711	6.6	5744	6746	446	406
11:55	175	1379	9.5	7453	7817	388	383
Mean		1111	7.9	7148	8002	393	380
Maximum		1811	9.5	9323	9723	473	443
Time at maximum		9:05	11:55	9:35	9:35	9:05	9:15

TABLE B-23. TEST NUMBER 10: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
9:00	0	41	0.2	43	12	413	399
9:10	10	719	0.8	3063	3489	389	416
9:20	20	873	1.7	3840	4364	348	385
9:30	30	859	2.4	4467	5527	359	413
9:40	40	841	2.4	4338	5182	381	428
9:50	50	798	2.8	4137	4962	357	395
10:00	60	789	2.4	3565	4315	458	449
10:10	70	1105	2.9	4161	4895	403	380
10:20	80	898	3.0	4055	4677	445	392
10:30	90	982	3.4	4294	5089	380	334
10:40	100	1203	4.5	4953	5766	396	329
10:50	110	1082	4.7	5049	6055	374	365
11:00	120	1210	5.0	4736	5602	411	340
11:10	130	768	3.8	4121	4986	431	383
11:20	140	829	3.9	3914	4629	323	349
11:30	150	750	3.3	3811	4590	435	368
11:40	160	756	3.3	3507	4354	381	458
11:50	170	740	3.1	3459	4491	467	475
Mean		847	3.0	3862	4610	397	392
Maximum		1210	5.0	5049	6055	467	475
Time at maximum		11:00	11:00	10:50	10:50	11:50	11:50

TABLE B-22. TEST NUMBER 9: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:05	0	587	0.8	1783	2081	714	640
13:15	10	790	1.3	2593	3214	696	667
13:25	20	930	1.5	3451	4001	613	593
13:35	30	896	2.1	3394	4034	522	349
13:45	40	941	2.5	3731	4479	613	564
13:55	50	470	0.9	2116	2544	765	707
14:05	60	798	1.7	2525	2937	655	664
14:15	70	767	1.9	2940	3503	453	403
14:25	80	847	2.0	3085	3722	802	780
14:35	90	825	1.7	2865	3321	742	696
14:45	100	1083	2.6	3527	4196	631	649
14:55	110	913	2.2	3664	4307	809	747
15:05	120	768	1.6	2886	3444	708	680
15:15	130	903	1.9	3550	4182	635	564
15:25	140	651	1.5	3173	3883	766	748
15:35	150	779	1.5	2887	3530	685	642
15:45	160	688	1.5	3037	3654	773	742
15:55	170	949	1.4	3288	3795	720	684
Mean		810	1.7	3027	3602	683	640
Maximum		1083	2.6	3731	4479	809	780
Time at maximum		14:45	14:45	13:45	13:45	14:55	14:25

TABLE B-21. TEST NUMBER 9: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:10	10	311	1.4	2374	2733	637	591
13:20	20	835	3.8	4144	4775	668	633
13:30	30	771	4.3	4639	5266	549	535
13:40	40	803	4.9	4952	5826	466	350
13:50	50	553	3.8	4576	5192	773	737
14:00	60	672	3.4	3916	4515	690	669
14:10	70	840	3.8	5137	6041	558	536
14:20	80	1049	5.0	5299	6124	595	516
14:30	90	726	3.5	4052	4566	786	746
14:40	100	1090	4.4	5341	6345	700	683
14:50	110	1185	5.3	5837	7037	708	667
15:00	120	781	3.9	4100	4878	798	780
15:10	130	703	3.8	3888	4777	673	622
15:20	140	533	3.5	3644	4238	783	736
15:30	150	525	3.1	2532	3209	751	740
15:40	160	742	4.2	3902	4558	579	564
15:50	170	670	4.2	3236	3990	776	728
Mean		752	3.9	4210	4945	676	637
Maximum		1185	5.3	5837	7037	798	780
Time at maximum		14:50	14:50	14:50	14:50	15:00	15:00

TABLE B-20. TEST NUMBER 8: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:50	5	31	0.2	223	165	427	408
9:00	15	531	0.3	2322	2741	497	451
9:10	25	599	0.8	2681	3128	505	504
9:20	35	692	1.4	2889	3392	593	558
9:30	45	754	1.7	2784	3275	499	483
9:40	55	893	2.3	2968	3475	459	452
9:50	65	788	1.9	2743	3254	482	473
10:00	75	776	1.8	3042	3555	409	401
10:10	85	666	1.9	2818	3379	458	361
10:20	95	786	2.1	3197	3928	538	497
10:30	105	798	1.8	3221	3858	506	507
10:40	115	922	2.3	3944	4683	502	487
10:50	125	814	2.4	3688	4385	486	475
11:00	135	1152	3.0	4314	4977	368	419
11:10	145	1034	2.8	3990	4712	483	470
11:20	155	1163	3.4	4430	5248	607	545
11:30	165	1039	2.8	3918	4528	608	590
11:40	175	963	3.0	3728	4545	585	502
11:50	185	****	****	****	****	564	527
12:00	195	****	****	****	****	668	633
12:10	205	****	****	****	****	572	581
12:20	215	****	****	****	****	554	491
12:30	225	****	****	****	****	598	624
12:40	235	****	****	****	****	431	378
Mean		801	2.0	3161	3735	517	492
Maximum		1163	3.4	4430	5248	668	633
Time at maximum		11:20	11:20	11:20	11:20	12:00	12:00

TABLE B-19. TEST NUMBER 8: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:45	0	26	0.1	86	66	464	464
8:55	10	660	1.3	3490	3958	439	443
9:05	20	626	2.1	3343	3851	547	536
9:15	30	591	2.8	4361	4857	559	500
9:25	40	673	3.3	4300	5064	540	515
9:35	50	708	3.5	4540	5011	499	468
9:45	60	1169	4.7	5318	6174	451	458
9:55	70	864	4.2	5624	6179	566	555
10:05	80	732	3.4	5108	5483	483	464
10:15	90	861	4.4	4811	5853	571	562
10:25	100	680	3.6	4680	5937	552	525
10:35	110	737	3.9	4902	5836	327	398
10:45	120	639	4.0	4835	5602	505	546
10:55	130	665	2.9	4264	4813	404	386
11:05	140	780	3.5	4441	4936	549	540
11:15	150	716	3.5	4773	5694	389	427
11:25	160	842	3.8	4878	5696	623	596
11:35	170	845	4.5	5622	6470	557	544
11:45	180	899	4.8	5405	6444	549	581
11:55	190	****	****	****	****	437	427
12:05	200	****	****	****	****	630	577
12:15	210	****	****	****	****	331	404
12:25	220	****	****	****	****	587	594
12:35	230	****	****	****	****	444	422
12:45	240	****	****	****	****	****	****
Mean		722	3.4	4462	5154	500	497
Maximum		1169	4.8	5624	6470	630	596
Time at maximum		9:45	11:45	9:55	11:35	12:05	11:25

TABLE B-18. TEST NUMBER 7: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
14:25	0	0.00	0.00
14:35	10	1.76	2.52
14:45	20	3.86	4.34
14:55	30	4.78	5.38
15:05	40	5.18	6.15
15:15	50	6.36	7.19
15:25	60	6.23	7.45
15:35	70	6.36	7.71
15:45	80	6.49	7.71
15:55	90	6.49	7.97
16:05	100	6.36	7.71
MEAN		4.89	5.83
Maximum		6.49	7.97
Time at Maximum		15:05	15:55

TABLE B-17. TEST NUMBER 6: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
10:30	5	186	1.8	578	642	523	514
10:40	15	1002	3.4	2710	3247	561	566
10:50	25	538	3.3	2245	2659	543	553
11:00	35	709	3.4	2633	3143	574	575
11:10	45	1114	3.5	2830	3314	527	549
11:20	55	395	2.0	1622	1964	605	590
11:30	65	528	2.3	1965	2339	591	581
11:40	75	614	2.7	2351	2771	568	586
11:50	85	665	2.7	2807	3316	568	581
12:00	95	669	2.9	2353	2814	587	592
12:10	105	605	2.5	2440	2937	548	582
12:20	115	515	3.0	2260	2748	559	525
12:30	125	375	2.9	1903	2293	515	499
12:40	135	539	2.6	1950	2333	588	559
12:50	145	535	2.7	1872	2232	541	550
13:00	155	801	3.1	2260	2671	577	605
13:10	165	571	2.5	1980	2360	630	645
13:20	175	587	2.5	1967	2368	480	507
13:30	185	799	2.8	2342	2874	494	523
Mean		618	2.8	2161	2580	557	562
Maximum		1114	3.5	2830	3316	630	645
Time at maximum		11:10	11:10	11:10	11:50	13:10	13:10

TABLE B-31. TEST NUMBER 14: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker-Deutz (No. 4)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
12:50	0	52	0.7	67	15	281	287
13:00	10	869	2.7	3868	4550	524	475
13:10	20	1031	4.3	9816	10516	519	526
13:20	30	951	4.2	9336	10184	537	501
13:30	40	873	4.3	9360	10063	559	488
13:40	50	954	4.8	10777	11354	509	444
13:50	60	1223	5.5	12010	13009	493	398
14:00	70	927	4.5	10067	10846	509	506
14:10	80	1032	5.0	10873	11346	494	500
14:20	90	935	4.4	9597	11084	576	515
14:30	100	1284	4.8	11437	12558	478	426
14:40	110	1157	4.5	11241	11772	437	381
14:50	120	1102	4.5	10853	11959	470	439
15:00	130	1324	4.9	10489	11642	461	448
15:10	140	882	3.7	8365	8941	565	495
15:20	150	956	4.3	9943	10533	592	543
15:30	160	1188	4.7	10992	11556	524	479
15:40	170	960	4.4	10072	10574	573	434
15:50	180	1263	4.8	10083	11278	565	519
Mean		998	4.3	9434	10199	509	463
Maximum		1324	5.5	12010	13009	592	543
Time at maximum		15:00	13:50	13:50	13:50	15:20	15:20

TABLE B-32. TEST NUMBER 15: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster Perkins (3)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
8:15	0	0.00	0.00
8:25	10	9.91	8.49
8:35	20	14.19	11.09
8:45	30	12.87	*****
8:55	40	13.13	*****
9:05	50	12.61	*****
9:15	60	9.17	10.05
9:25	70	11.81	11.09
9:35	80	12.61	13.17
9:45	90	12.08	14.21
Mean		10.83	9.73
Maximum		14.19	14.21
Time at Maximum		8:35	9:45

TABLE B-33. TEST NUMBER 16: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Hyster Perkins (3)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
12:34	0	0.00	0.00
12:44	10	.91	.95
12:54	20	3.89	4.33
13:04	30	4.69	4.85
13:14	40	4.42	4.85
13:24	50	4.69	5.11
13:34	60	4.69	5.11
13:44	70	4.95	5.63
13:54	80	4.69	5.37
14:04	90	5.21	5.63
Mean		3.81	4.18
Maximum		5.21	5.63
Time at Maximum		14:04	13:44

TABLE B-34. TEST NUMBER 17: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster Perkins (3)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
14:34	0	1.78	.95
14:44	10	3.63	3.55
14:54	20	5.21	5.11
15:04	30	5.21	5.37
15:14	40	4.95	5.63
15:24	50	5.21	6.93
15:34	60	6.27	6.93
15:44	70	6.80	7.19
15:54	80	6.80	7.71
16:04	90	7.06	7.71
16:14	100	6.53	7.45
Mean		5.40	5.87
Maximum		7.06	7.71
Time at Maximum		16:04	15:54

TABLE B-35. TEST NUMBER 18: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
9:40	0	172	1.3	598	555	242	226
9:50	10	987	6.4	4781	5434	342	353
10:00	20	545	4.8	4563	5058	499	428
10:10	30	981	7.4	5647	6751	415	415
10:20	40	786	7.6	5360	5824	494	448
10:30	50	773	8.2	5019	5611	468	352
10:40	60	965	7.3	5122	6155	345	353
10:50	70	1550	10.1	8436	10157	379	370
11:00	80	1110	9.0	6542	7006	437	381
11:10	90	930	7.0	6438	7258	403	343
11:20	100	300	2.3	3057	3481	476	402
11:30	110	****	****	****	****	****	****
11:40	120	****	****	****	****	****	****
11:50	130	****	****	****	****	****	****
Mean		827	6.5	5050	5754	409	370
Maximum		1550	10.1	8436	10157	499	448
Time at maximum		10:50	10:50	10:50	10:50	10:00	10:20

TABLE B-36. TEST NUMBER 18: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
9:45	5	1331	2.6	9581	9787	315	346
9:55	15	1118	3.2	10288	11499	390	388
10:05	25	985	3.2	10606	11710	510	476
10:15	35	1302	4.0	12792	14282	452	422
10:25	45	1515	4.8	12999	13900	420	420
10:35	55	1710	5.0	13965	15544	437	357
10:45	65	1497	4.6	13709	13991	357	330
10:55	75	1320	4.6	14126	14824	437	401
11:05	85	1124	3.8	11319	12553	549	423
11:15	95	1105	3.1	9998	10522	489	427
11:25	105	968	2.6	11069	12656	566	495
11:35	115	1293	3.4	12107	13970	272	269
11:45	125	1560	4.4	12010	14091	399	385
11:55	135	1583	4.8	12589	14008	356	340
12:05	145	1291	4.1	12579	12983	495	437
12:15	155	1022	3.0	8820	9555	393	362
12:25	165	1439	3.9	12095	13380	470	395
12:35	175	1149	3.3	10139	10771	474	447
12:45	185	****	****	****	****	****	****
12:55	195	****	****	****	****	****	****
Mean		1295	3.8	11711	12779	432	395
Maximum		1710	5.0	14126	15544	566	495
Time at maximum		10:35	10:35	10:55	10:35	11:25	11:25

TABLE B-37. TEST NUMBER 19: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:30	0	106	0.3	203	158	441	363
13:40	10	1018	2.6	6796	7389	524	413
13:50	20	1146	3.5	9250	9682	374	298
14:00	30	1246	4.5	11953	13390	371	303
14:10	40	1605	5.0	11684	12982	511	301
14:20	50	1445	5.0	12379	13215	434	437
14:30	60	970	3.3	9776	10692	428	296
14:40	70	919	3.0	9558	10332	445	503
14:50	80	1029	2.7	8975	9428	455	376
15:00	90	630	1.9	8436	9065	496	408
15:10	100	1471	4.1	11004	11962	448	453
15:20	110	1228	4.2	10812	11453	465	421
15:30	120	1087	4.5	9189	10565	443	433
15:40	130	890	3.3	9417	10714	515	441
15:50	140	1208	3.5	11263	12361	534	434
16:00	150	1319	4.0	10027	10710	475	394
16:10	160	1224	3.8	11074	11636	454	253
16:20	170	1334	3.9	11603	13063	507	328
Mean		1104	3.5	9633	10489	462	381
Maximum		1605	5.0	12379	13390	534	503
Time at maximum		14:10	14:10	14:20	14:00	15:50	14:40

TABLE B-38. TEST NUMBER 19: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (A)

Sampling location: Rear

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:35	5	791	2.0	5282	5464	496	394
13:45	15	937	3.5	8901	9589	409	353
13:55	25	1045	4.9	10763	12063	426	314
14:05	35	1024	4.7	11325	12517	530	425
14:15	45	1067	5.0	11004	12059	432	381
14:25	55	1033	4.2	11246	12032	468	394
14:35	65	805	3.4	8934	9787	424	272
14:45	75	811	2.7	9184	10037	463	446
14:55	85	853	2.7	9338	10011	456	410
15:05	95	985	2.9	8086	8713	421	300
15:15	105	1242	4.6	11120	12327	499	395
15:25	115	1060	4.5	10580	11340	531	475
15:35	125	751	3.5	9600	10413	522	429
15:45	135	841	3.2	8930	9858	543	431
15:55	145	863	3.1	9437	10259	521	451
16:05	155	1019	4.3	10418	11253	543	500
16:15	165	861	3.5	9674	10480	446	171
16:25	175	941	3.3	8876	9597	481	72
Mean		940	3.7	9594	10433	478	367
Maximum		1242	5.0	11325	12517	543	500
Time at maximum		15:15	14:15	14:05	14:05	16:05	16:05

TABLE B-39. TEST NUMBER 20: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Hyster/Isuzu (2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
9:55	0	0.00	0.00
10:05	10	3.58	4.59
10:15	20	5.71	6.71
10:25	30	6.51	6.71
10:35	40	6.23	7.23
10:45	50	6.23	7.23
10:55	60	6.23	6.71
11:05	70	5.71	5.91
11:15	80	4.91	5.65
11:25	90	5.18	6.18
11:35	100	5.18	5.65
11:45	110	5.18	5.91
Mean		5.05	5.71
Maximum		6.51	7.23
Time at Maximum		10:25	10:35

TABLE B-40. TEST NUMBER 21: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Hyster/Isuzu (2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
12:25	0	.64	.63
12:35	10	.37	1.43
12:45	20	1.98	4.07
12:55	30	4.11	4.88
13:05	40	4.65	5.65
13:15	50	5.18	5.39
13:25	60	5.45	5.39
13:35	70	5.45	5.65
13:45	80	4.65	5.65
13:55	90	5.18	6.18
14:05	100	5.18	5.65
14:15	110	4.65	6.18
Mean		3.96	4.73
Maximum		5.45	6.18
Time at Maximum		13:25	13:55

TABLE B-41. TEST NUMBER 22: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
15:00	0	0.00	0.00
15:10	10	2.51	4.07
15:20	20	4.65	5.65
15:30	30	4.65	5.65
15:40	40	5.18	6.18
15:50	50	4.91	5.91
16:00	60	4.91	5.91
16:10	70	5.18	6.18
16:20	80	5.71	6.44
16:30	90	6.23	6.18
Mean		4.39	5.22
Maximum		5.71	6.44
Time at	Maximum	16:20	16:20

TABLE B-42. TEST NUMBER 23: CONTINUOUS AIR MONITORING DATA

Operation: Unloading

Vehicle: Baker/Deutz (4)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
10:15	0	0.00	0.00
10:25	10	7.42	7.80
10:35	20	8.14	9.25
10:45	30	9.59	10.51
10:55	40	9.77	10.87
11:05	50	11.39	11.24
11:15	60	12.84	12.50
11:25	70	13.38	14.31
11:35	80	13.02	15.04
11:45	90	13.56	14.86
11:55	100	11.03	15.04
Mean		10.01	11.04
Maximum		13.56	15.04
Time at Maximum		11:45	11:35

TABLE B-43. TEST NUMBER 24: CONTINUOUS AIR MONITORING DATA

Operation: Loading

Vehicle: Baker/Deutz (4)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
13:05	0	.92	1.10
13:15	10	****	1.10
13:25	20	3.45	5.63
13:35	30	6.70	8.70
13:45	40	8.50	10.69
13:55	50	10.13	13.23
14:05	60	11.76	13.41
14:15	70	12.48	13.41
14:25	80	12.30	13.41
14:35	90	12.30	13.05
14:45	100	****	****
14:55	110	11.57	12.86
15:05	120	12.12	12.86
15:15	130	10.67	10.87
Mean		8.73	9.37
Maximum		12.48	13.41
Time at Maximum		14:15	14:05

TABLE B-44. TEST NUMBER 25: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:50	0	37	4.1	117	70	258	230
9:00	10	1738	1.2	8687	9728	405	319
9:10	20	1719	1.8	8270	9997	356	340
9:20	30	1341	1.9	9627	9886	357	328
9:30	40	1865	2.6	11348	12217	339	240
9:40	50	1864	2.5	10867	11576	384	104
9:50	60	1826	3.9	11134	11907	325	153
10:00	70	1829	4.0	10715	11940	375	176
10:10	80	1936	4.7	11163	11980	344	88
10:20	90	****	****	****	****	428	133
10:35	105	1763	4.6	10105	10805	395	264
10:45	115	1096	2.7	9403	9687	318	213
10:55	125	1953	4.9	10895	12076	412	261
11:05	135	1978	4.8	11013	11726	433	313
11:15	145	1724	3.8	10766	11951	450	325
11:25	155	2175	4.3	11192	12227	335	288
11:35	165	1715	3.6	10374	10928	336	354
11:45	175	1905	4.5	11291	12273	459	347
11:55	185	1466	3.4	10672	11860	353	338
Mean		1663	3.5	9868	10713	372	253
Maximum		2175	4.9	11348	12273	459	354
Time at maximum		11:25	10:55	9:30	11:45	11:45	11:35

TABLE B-45. TEST NUMBER 25: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
13:05	0	74	0.5	158	125	293	227
13:15	10	684	1.0	1366	1880	278	258
13:25	20	717	2.2	5483	5721	337	289
13:35	30	1008	3.0	7592	8152	400	278
13:45	40	1101	3.6	8919	9320	408	354
13:55	50	1272	3.8	9418	10232	429	347
14:05	60	863	3.0	7694	8138	439	273
14:15	70	1181	3.1	7473	7905	432	335
14:25	80	1170	3.0	6815	7280	461	403
14:35	90	941	2.7	7043	7574	557	520
14:45	100	1087	2.7	7379	7668	563	466
14:55	110	1476	3.9	8800	9333	402	250
15:05	120	958	2.5	7074	7439	507	355
15:15	130	****	****	6827	7462	458	11
Mean		964	2.7	6574	7016	426	312
Maximum		1476	3.9	9418	10232	563	520
Time at maximum		14:55	14:55	13:55	13:55	14:45	14:35

TABLE B-46. TEST NUMBER 26: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Perkins (No. 3)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:55	5	449	5.6	3391	3644	314	245
9:05	15	1965	12.5	10431	11873	320	258
9:15	25	1126	9.8	7092	7732	356	375
9:25	35	869	9.3	9053	10159	397	308
9:35	45	****	****	****	****	****	****
9:45	55	****	****	****	****	****	****
9:55	65	****	****	****	****	****	****
Mean		1102	9.3	7492	8352	347	296
Maximum		1965	12.5	10431	11873	397	375
Time at maximum		9:05	9:05	9:05	9:05	9:25	9:15

TABLE B-47. TEST NUMBER 27: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
8:22	0	0.00	0.00
8:32	10	3.81	4.90
8:42	20	5.98	6.53
8:52	30	6.70	7.62
9:02	40	6.88	7.44
9:12	50	7.06	7.98
9:22	60	6.52	7.62
9:32	70	6.70	7.80
9:42	80	6.70	8.16
9:52	90	7.06	8.34
10:02	100	7.42	8.7
10:12	110	7.6	9.43
10:22	120	7.96	8.16
Mean		6.18	7.13
Maximum		7.96	9.43
Time at Maximum		10:22	10:12

TABLE B-48. TEST NUMBER 28: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (No. 4)

Magazine: Igloo (C)

Sampling location: Center

Time	Elapsed Time	NO (PPM)	NOx (PPM)
12:21	0	0.00	0.00
12:31	10	5.25	7.07
12:41	20	12.12	12.14
12:51	30	16.81	17.39
13:01	40	17.17	17.93
Mean		10.27	10.91
Maximum		17.17	17.93
Time at Maximum		13:01	13:01

TABLE B-49. TEST NUMBER 29: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Hyster/Isuzu (No. 2)

Magazine: Stradley (B)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
11:00	0	1179	2.0	2127	2536	373	276
11:10	10	1251	2.6	3337	3641	441	329
11:20	20	1577	3.2	3779	4561	393	382
11:30	30	1354	3.5	3730	4218	400	290
11:40	40	1232	3.4	3166	3665	463	382
11:50	50	1682	4.4	3792	4572	384	406
12:00	60	1271	3.4	3292	4157	324	256
12:10	70	1521	4.0	3613	4289	214	288
12:20	80	1122	3.0	3170	3640	367	387
12:30	90	982	2.9	3252	3721	155	256
12:40	100	1123	3.8	4133	4571	269	219
12:50	110	1094	3.9	4091	4912	321	315
13:00	120	1311	4.4	4397	5190	307	326
13:10	130	1192	3.7	4039	4702	307	279
13:20	140	1446	4.8	5154	6058	369	270
13:30	150	1608	5.2	5278	6217	349	245
13:40	160	1598	5.9	5963	7160	351	256
13:50	170	1747	5.8	6004	7010	359	250
Mean		1349	3.9	4018	4712	341	301
Maximum		1747	5.9	6004	7160	463	406
Time at maximum		13:50	13:40	13:50	13:40	11:40	11:50

TABLE B-50. TEST NUMBER 30: CONTINUOUS AIR MONITORING DATA

Operation: Warehousing

Vehicle: Baker/Deutz (4)

Magazine: Stradley (A)

Sampling location: Forward

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	NO (PPB)	NOX (PPB)	AIR1 (CFM)	AIR2 (CFM)
8:50	0	37	4.1	117	70	258	230
9:00	10	1738	1.2	8687	9728	405	310
9:10	20	1719	1.8	8270	9997	356	340
9:20	30	1341	1.9	9627	9886	357	328
9:30	40	1865	2.6	11348	12217	339	248
9:40	50	1864	2.5	10867	11576	384	104
9:50	60	1826	3.9	11134	11907	325	153
10:00	70	1829	4.0	10715	11940	375	176
10:10	80	1936	4.7	11163	11980	344	88
10:20	90	****	****	****	****	428	133
10:35	105	1763	4.6	10105	10805	395	264
10:45	115	1096	2.7	9403	9687	318	213
10:55	125	1953	4.9	10885	12076	412	261
11:05	135	1978	4.8	11013	11726	433	313
11:15	145	1724	3.8	10766	11951	450	325
11:25	155	2175	4.3	11192	12227	335	288
11:35	165	1715	3.6	10374	10928	336	354
11:45	175	1905	4.5	11291	12273	459	347
11:55	185	1466	3.4	10672	11860	353	338
Mean		1663	3.5	9868	10713	372	253
Maximum		2175	4.9	11348	12273	459	354
Time at maximum		11:25	10:55	9:30	11:45	11:45	11:35

APPENDIX C

CHARACTERISTICS OF TEST FUEL

TABLE C-1. TEST FUEL DATA

Characteristic	Low sulfur EPA DF-2 certification		High sulfur MIL-F-46162B(ME)	
	Fuel specifications	Analysis	Fuel specifications	Analysis
Gravity, API	33-37	33.1	N/A	32.9
Density, g/ml	NA	NA	Report	0.8603
Flash Point, °C	49	66	Report	70
Cloud Point, °C	NA	NA	-13	-18
Pour Point, °C	NA	NA	-18	-20
Viscosity, cSt, at 40°C	2.0-3.2*	3.0	1.9-4.1	2.66
Distillation, °C				
IBP	171-204	198	Report	193
10% Recovered	204-238	239	Report	228
50% Recovered	243-282	273	245-285	264
90% Recovered	288-321	312	330-387	319
EBP	304-349	338	385 max	357
Carbon Residue (10% bottom)	NA	NA	0.20 max	0.16
Ash, % wt. max	NA	NA	0.02	0
Cu Strip Corrosion	NA	NA	1 max	1A
Acceleration stability mg/100 ml	NA	NA	1.5 max	1.83
Neutral Number	NA	NA	0.2	0.04
Aromatics, % vol	27.5 min	37.8	Report	37.9
Sulfur, %	0.2-0.5	0.4	0.95-1.05	1.03
Cetane Number	42-50	47.1	40-45	53
Particulate, mg/l	NA	NA	10 max	10

*Viscosity at 37.8°C (100°F).

APPENDIX D

DAILY METEOROLOGICAL CONDITIONS

TABLE D-1. DAILY METEOROLOGICAL CONDITIONS

Test number	Test date	Mean temperature (degrees F)	Mean barometric pressure (torr)	Wind speed (mph)	Wind direction
1	07/23/84	97	765	8	SW
2	07/24/84	86	765	6	NE
3	07/24/84	86	768	6	NE
4	07/25/84	72	767	2	W
5	07/25/84	72	767	2	NE
6	07/26/84	67	764	5	E
7	07/26/84	67	764	5	N
8	07/27/84	74	766	5	NE
9	07/27/84	74	766	7	N
10	07/30/84	82	767	3	SE
11	07/30/84	82	767	6	S
12	07/30/84	82	767	6	S
13	07/31/84	89	764	2	S
14	07/31/84	89	764	7	SW
15	07/31/84	89	764	1	S
16	07/31/84	89	764	7	SW
17	07/31/84	89	764	8	SW
18	08/01/84	90	764	5	SW
19	08/01/84	90	764	7	SW
20	08/01/84	90	764	5	SW
21	08/01/84	90	764	7	SW
22	08/01/84	90	764	7	S
23	08/02/84	90	764	2	S
24	08/02/84	90	765	3	S
25	08/03/84	99	765	4	SW
26	08/03/84	99	763	4	SW
27	08/03/84	99	763	4	SW
28	08/03/84	99	763	6	W
29	08/03/84	99	763	5	W

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A153 C?L	3. RECIPIENT'S CATALOG NUMBER
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16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Diesel engine exhaust pollutants	Nitrogen dioxide	Sulfur dioxide	Industrial hygiene
	Nitric oxide	Particulate	Odorants
Carbon monoxide	Sulfates	PAH	
Nitrogen oxides (NO_x)	Sulfites	Worker exposure	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Indoor air quality and worker exposures were monitored in Stradley and Igloo-type ammunition magazines during the use of diesel-powered forklifts. The monitoring took place during storage and handling operations. The test vehicles included a Still forklift powered by a Deutz (F3L912 W) engine, a Hyster forklift powered by an ISUZU (C240) engine, a Hyster forklift powered by a Perkins (4.154) engine, and a Baker forklift powered by a Deutz (F3L912 W) engine. Both breathing zone (personal) and continuous (area) monitoring data were collected during the operation of these vehicles. Total suspended particulates,

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) polycyclic aromatic hydrocarbons (PAH), carbon monoxide, sulfates, sulfites, sulfur dioxide, nitrogen dioxide, nitric oxide, oxides of nitrogen and odorants were monitored.

The test results indicate that the impact of diesel exhaust on breathing zone exposures and magazine air quality depends largely on the type of operation being performed and the type of magazine being used. Of the two operating scenarios investigated (i.e., loading/unloading and warehousing), warehousing presents the greater potential risk to the health and safety of Army personnel. Of the two magazines investigated (i.e., Stradley and Igloo-types), Igloo-type structures of the size encountered in this study are likely to contribute to a hazardous situation.

Breathing zone exposures and magazine air quality data were compared with the OSHA permissible exposure levels and ACGIH threshold limit values. Under the operating conditions, ventilation, and temperatures experienced during the test; nitrogen dioxide, nitric oxide, and carbon monoxide may pose a health risk to Army personnel in small structures similar in size and design to the Igloo-type magazines.

A performance hierarchy can be suggested from the results of the air monitoring data. The Still-Deutz and Hyster-Isuzu vehicles appear to have out performed the Hyster-Perkins and Baker-Deutz forklifts. Under the conditions tested the Still-Deutz and Hyster-Isuzu did not exceed any of the OSHA permissible exposure limits for the exhaust components measured.

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